

12

DASIAC TN 75-2

ADA 038738

# COMBINED AIRBLAST AND INCENDIARY EFFECTS FROM NUCLEAR WEAPONS ON URBAN AREAS

General Electric Company-TEMPO  
DASIAC  
816 State Street  
Santa Barbara, California 93101

August 1975

Technical Note

CONTRACT No. DNA 001-75-C-0023

AD No. \_\_\_\_\_  
DDC FILE COPY

APPROVED FOR PUBLIC RELEASE;  
DISTRIBUTION UNLIMITED.

DDC  
APR 27 1977  
A

THIS WORK SPONSORED BY THE DEFENSE NUCLEAR AGENCY  
UNDER RDT&E RMSS CODE B337076464 P99QAXDC00803 H2590D.

Prepared for  
Director  
DEFENSE NUCLEAR AGENCY  
Washington, D. C. 20305

Destroy this report when it is no longer  
needed. Do not return to sender.



SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

4E



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. ABSTRACT (Continued)

cont.

→ distance from ground zero. Results from previous studies are used to apply the technique to single-family residential areas. The synergistic effects of airblast and thermal radiation and fires are analyzed and illustrated. It is concluded that for many conditions of interest (moderate height-of-burst, megaton weapon, reasonably clear atmospheric conditions and single-family residential areas), airblast may blow out initial fires so as to significantly reduce the fraction of houses burned up in areas suffering a relatively high degree of burnout; but areas of, for example, 25% to 40% burnout may be unaffected because they occur beyond the range at which airblast is assumed sufficient to extinguish fires.



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

## PREFACE

The author wishes to acknowledge the significant contributions of Kenneth Kaplan whose pertinent experience and constructive criticism enabled the analysis carried out and presented in this report to be done in a more comprehensive, lucid, and authoritative manner.

ACCESSION FOR	
NTIS	NTIS SECTION <input checked="" type="checkbox"/>
DDC	DDC SECTION <input type="checkbox"/>
UNCLASSIFIED	UNCLASSIFIED <input type="checkbox"/>
JUSTIFICATION	
<i>Ref. 1 removed</i>	
<i>Copy. Phon. call</i>	
INSTRUCTIONS TO REVISION	
A	

Report No. DASIAC TN 75-2  
Delete classified reference per Ms.  
Egan, DNA

## CONTENTS

	PAGE
SECTION 1- INTRODUCTION	3
SECTION 2- AIRBLAST ENVIRONMENT AND EFFECTS	6
Airblast Phenomena	6
Airblast Effects on Buildings	7
Airblast Peak Overpressure Levels	11
Airblast Damage Zones	13
SECTION 3- THERMAL RADIATION ENVIRONMENT AND EFFECTS	19
Thermal Radiation Phenomena	19
Index of Thermal Damage	22
Thermal Radiation Effects on Urban Areas	22
SECTION 4- COMBINED AIRBLAST AND THERMAL DAMAGE	34
Influence of Thermal Radiation on Airblast Damage	36
Influence of Airblast on Damage by Fires	37
Extinguishment of Primary Fires by Airblast	37
Secondary Fires	47
Other Synergistic Effects of Airblast	50
SECTION 5- CONCLUSIONS AND RECOMMENDATIONS	51
REFERENCES	56

## SECTION 1

### INTRODUCTION

At the request of the Defense Civil Preparedness Agency (DCPA), the Defense Nuclear Agency (DNA) authorized DASIAC, the Department of Defense Nuclear Information and Analysis Center, to conduct a study of airblast and thermal effects from nuclear weapons.

The DCPA requested that the study:

1. "Describe the environment produced by a nuclear detonation at various regions circling ground zero. Specifically, mention the possible synergistic effects of airblast and nuclear thermal radiation."
2. "Describe the manner by which these regions may be modified by individual and mass fire effects during various time periods after detonation."
3. "Relate (1) and (2) to actual observations made of nuclear detonations and natural disasters."

All of the above items could not be addressed within the constraint of a low level-of-effort. In particular, mass fire phenomena and effects are not included in this study. Mass fires seem to require a different type of analysis in which a study such as this could be used as an input. Actual observations of nuclear explosions and natural disasters are included only indirectly when they were used as parts of the analysis in the references used in this study.

The work was done largely through a review of germane reports available at DASIAC. The major sources of information included reports published by DNA, Stanford Research Institute (SRI), the Illinois Institute of Technology Research Institute (IITRI), and URS Research (URS). Because of the survey nature of the study, only a limited amount of original work was done, mostly in the form of analyzing and synthesizing other investigators' results into forms suitable for presentation.

The airblast environment and effects are addressed in Section 2. The airblast phenomena are described. Vulnerability levels of types of buildings and their major components (roofs, walls, etc.) to airblast are summarized, and a height-of-burst (HOB) is chosen which maximizes the region around ground zero that would be subject to relatively high overpressures for structural damage (5 to 10 psi). Many of the results are not especially sensitive to HOB and the analysis could be repeated for other HOBs if desired. The airblast environment is illustrated and airblast damage zones are defined and displayed as a function of weapon yield and distance from ground zero for typical urban areas and for single-family residential areas.

Section 3 addresses the thermal radiation environment and effects. The thermal radiation phenomena are described and the thermal environment is illustrated in terms of radiant energy and also as multiples of an index of fire potential, the "critical ignition exposure" (CIE) of newspaper. A technique is described which permits the fraction of structures burned up (not including mass fire spread into areas where primary ignitions have not occurred) to be displayed as a function of weapon yield and distance from ground zero. Results of previous studies are used to apply the technique to single-family residential areas. Information needed to apply the technique to other types of areas appears to be lacking.

The combined effects of the airblast and thermal environments on single-family residential areas are analyzed in Section 4. (Other types of areas can be analyzed by the techniques described if the necessary input data are available). Possible modification of the airblast environment and effects by the thermal pulse are examined. The significance of airblast blowout of initial ignitions and the creation of airblast-induced secondary fires is analyzed and illustrated. Other effects of airblast which affect the local spread of fires are discussed.

Section 5 contains the conclusions and recommendations of the author. The major conclusion is that for many conditions of interest



to the DCPA (megaton weapon at moderate height-of-burst, generally clear atmospheric conditions, and U.S. single-family residential areas), airblast may blow out initial fires so as to significantly reduce the fraction of homes burned up in areas suffering a relatively high degree of burnout; but areas of lesser fire damage (25-40 percent burnout) are unaffected because they are beyond the range at which it is assumed airblast overpressure is sufficient to blow out fires. Airblast blow-out of fires becomes relatively more significant at lower weapon yields.

Other conditions of interest to other agencies (e.g., a tactical nuclear engagement, a European theater of operations, or a MIRV attack on U.S. cities) require data and analysis tailored to the specific situations.

## SECTION 2

### AIRBLAST ENVIRONMENT AND EFFECTS

#### AIRBLAST PHENOMENA

The blast or shockwave in air (airblast) propagating from a nuclear explosion (burst) in the "free field" (that is, in the absence of reflecting surfaces) is characterized by an initial increase in pressure over ambient pressure accompanied by air flow (wind) in the direction of wave propagation. The initial pressure rise at the shock front is extremely rapid—ideally instantaneous, though real-gas effects result in a shock front of finite width. The characteristics of the air flow behind the front are directly related to shockwave overpressure and are usually described by the "dynamic pressure" defined as  $\rho u^2/2$ , where  $\rho$  is the density behind the front and  $u$  is the flow velocity. Behind the shock front, overpressures and dynamic pressures decrease with time, returning to ambient pressure following a negative phase where the "overpressure" falls below ambient and air flow reverses direction.

The airblast from a burst that takes place above the ground surface (an airburst) reflects from the ground, initially undergoing "regular" reflection (in which the shockwave pattern consists of two shockwaves, an incident and a reflected wave), and at greater distances from ground zero undergoing "Mach reflection". In Mach reflection the reflected wave of regular reflection propagates faster through the air heated by the passage of the incident shockwave and "catches up" and "fuses" with the incident wave to form a stronger airblast with a sharp rising shock front and airflow generally parallel to the ground surface, i.e., a Mach stem.

The thermal pulse from an airburst, which propagates essentially at the speed of light, will always arrive before the airblast. Over many types of ground surface, the interaction of this pulse with the ground so modifies the air above it that the later arriving airblast changes form considerably. The front is no longer sharp but rises slowly to a smaller value of peak overpressure, forming what is called a precursor wave. As discussed in Section 4, no precursor is expected to form for the conditions of interest to this report.

### AIRBLAST EFFECTS ON BUILDINGS

When airblast strikes, for example, the wall of a building, reflected waves are formed and the pressure on the wall builds up almost instantaneously to a value which is usually at least double the incident peak overpressure, depending on the magnitude of the airblast and its angle of incidence with the wall. Rarefaction waves from the edges of the building and from open or broken windows or doors propagate into the region of high reflected pressure, and reflect and re-reflect from each other in a complex pattern. This has the effect of reducing the overall pressure on the wall, albeit with some substantial oscillation, while the airblast proceeds to encompass the entire building.

If the duration of the airblast is long enough and the walls of the building do not immediately collapse, pressures on upstream walls of the building become smoother and decrease to values somewhat larger than the incident overpressure (the difference being due to the wind loading; that is, the contribution of dynamic pressure), and pressures on downstream faces attain values somewhat lower than incident overpressure. During this time, of course, air flow has been entering the building through open or broken windows and doors and, if strong enough, this air flow can cause considerable damage by destroying partitions, throwing furniture about, etc., inside the building.

Building walls, and most structures, fail because of the effects of overpressure. Some structures and structural elements — chimneys, building frames and the like—are enveloped so quickly by the airblast that the primary force tending to cause failure is that from the blast wind or dynamic pressure. However, if a precursor is not formed, the shock-wave has a "near-ideal" shape where there is a fixed relationship between dynamic pressure and overpressure at the shock front. It is thus possible, for those cases in which dynamic pressure is the principal damaging agent, to state the overpressure that will generate a particular level of dynamic pressure, and thus a particular level of damage. By this means, only a single blast parameter, peak overpressure, need be used as an index to relate damage to airblast characteristics. That is the approach adopted here.

Various authors and investigators have evaluated and categorized airblast damage to buildings and building components in different ways, making comparisons among them somewhat difficult. In addition, results of different studies sometime disagree. General patterns are discernible, however, from which it is possible to describe broad categories of damage and relate these to peak overpressures.

Reference 1 and Glasstone (Reference 2) categorize structures as overpressure sensitive or dynamic pressure sensitive, and then predict the average values of these parameters which will produce "light" (requiring minor repairs), "moderate" (requiring major repairs), or "severe" (collapse or near-collapse) damage to types of buildings. These references are primarily interested in overall damage and do not cover in a comprehensive manner the vulnerability of building components such as roofs or walls.

Predictions of loading and response of building components are primarily based on observations of airblast damage to buildings at

Hiroshima and Nagasaki, nuclear and high-explosive field tests involving building components and entire buildings, and shock tunnel and other laboratory tests. Analytical and computer code techniques have been used to predict and verify empirical results. Reference 5 summarizes the results of shock tunnel experiments on wall panels, including pre-loaded and arched wall panels, at URS Research Corporation (URS). Stanford Research Institute (SRI) has produced a series of reports describing the development of mathematical models and computer codes dealing with structural failure, such as Reference 6.

In an SRI study (Reference 7), the failure criteria of various building components and the composite structure are estimated subjectively, based on the judgment of people experienced in nuclear airblast damage experiments and analysis. Results are presented for a variety of building types for various probabilities of failure. The damage measure used is the value of peak overpressure which will produce a certain probability of defined component failure, even though that component may fail due to dynamic pressure or combined dynamic pressure and overpressure.

The results of airblast damage to residential dwellings by nuclear and high-explosive experiments have been summarized by URS in Reference 8. Although the variety of dwelling types and incident airblast parameters of interest are limited, these tests furnish direct empirical data regarding the vulnerability of full-scale Western-type residences to airblast. (Extensive fire damage tended to mask the separate effect of airblast on residential structures at both Hiroshima and Nagasaki.)

Table 1 summarizes the broad conclusions of the above referenced reports. It must be emphasized that the values in Table 1 are intended to represent a general consensus of a majority of studies and investigations of structural failure. They may be questioned in detail, however, because not all sources are in agreement. For example, values of overpressure for particular levels of damage from References 1 and 2

Table 1. Summary of airblast peak overpressures (in psi) corresponding to collapse or near-collapse of buildings and building components.

	WINDOWS AND DOORS	INTERIOR PARTITIONS	ROOF	FLOORS	EXTERIOR WALLS	COMPOSITE BUILDING
Wood Frame Buildings	< 1	< 1-2 (Refs 5 & 7)	2-4 (Refs 7 & 8)	2-4 (Refs 7 & 8)	2-4 <sup>a</sup>	3-4 (Refs 1,2,8) <sup>b</sup>
Load-Bearing Masonry Wall Buildings (not reinforced)	< 1	< 1-2 frame (Refs 5 & 7) 2-4 masonry (Ref 7)	2-4 (Refs 7 & 8)	2-4 (Refs 7 & 8)	2-5 (Refs 5,7,8)	2-5 (Refs 1,2,7,8)
Load-Bearing Masonry Wall Buildings (non-ventilator type buildings)	< 1	4-6 (Ref 7)	7-15 (Refs 7 & 8)	6-8 (Ref 7)	7-12 (Refs 1,2,7)	7-12 (Refs 1,2,7)
Reinforced-Concrete Wall Buildings	< 1				10-13 (Refs 1,2)	10-13 (Refs 1,2)
Steel-Frame Industrial Type Buildings	< 1		2-3 (Ref 7)		< 1-2 <sup>c</sup> (Refs 1,2,7)	5-10 (collapse light frame) (Refs 1,2,7) <sup>c</sup> 9-14 (collapse heavy frame) (Refs 1,2,7) <sup>d</sup>
Multistory Steel-Frame Office and Apartment Buildings (light walls) <sup>g</sup>	< 1	< 1-2 frame (Refs 5 & 7) 2-4 masonry (Ref 7)	8-15 (Ref 7)		< 1-2 <sup>e</sup> light (Refs 1,2,7); 2-5 heavy (Ref 7)	13-18 (earthquake construction) 11-15 (non-earthquake construction) <sup>f,g</sup>
Multistory Reinforced-Concrete Frame Office and Apartment Buildings (light walls) <sup>g</sup>	< 1	< 1-2 frame (Refs 5 & 7) 2-4 masonry (Ref 7)	8-15 (Ref 7)		< 1-2 <sup>e</sup> light (Refs 1,2,7); 3-10 heavy <sup>g</sup> (Ref 7)	13-15 (earthquake construction) 11-14 (non-earthquake construction) <sup>f,g</sup>

2 There is little consensus among references. Reference 7 indicates wood siding walls fail at between 1.5-3 psi and masonry between 2-3 psi. Shock tunnel tests (Reference 5) indicate masonry walls fail at from less than 1 to 2 psi. In field tests (Reference 8), no walls failed below 2-3 psi, while collapse was complete at 5 psi.

3 Reference 7 predicts collapse at 1.5 to 3 psi.

4 Dynamic-pressure-sensitive frame predicted to collapse at approximately 5, 8 and 10 psi for 30-MT, 1-MT and 30-kt weapons, respectively.

5 Dynamic-pressure-sensitive frame predicted to collapse at approximately 10, 12 and 14 psi for 30-MT, 1-MT and 30-kt weapons respectively. Reference 7 predicts collapse at 6-8 psi for negaton weapon.

6 Facing exposure. Reference 7 predicts 2-4 psi for side and rear walls.

7 References 7 and 10 predict collapse of frame at 8 to 12 psi.

8 For heavy walls, Reference 7 predicts collapse of frame at 6 to 10 psi for negaton weapons.

are generally higher than those from the latest tests. Also, for example, exterior walls of similar buildings, or even in the same building, may fail at greatly different peak overpressures, depending on construction techniques and the particular materials used, as discussed in Reference 9.

#### AIRBLAST PEAK OVERPRESSURE LEVELS

For so-called "near ideal" conditions that do not give rise to precursor effects, Figure 1, known as a height-of-burst (HOB) chart, shows the relationship between HOB and ground distance (the distance from ground zero) scaled to a 1-kt weapon that would give rise to shockwaves with particular values of peak overpressure in the 1- to 12-psi overpressure range. Figure 1 can be applied to other weapon yields by multiplying all distances by the cube root of the weapon yield in kilotons. The dashed line shows the boundary between conditions for the occurrence of regular reflection and Mach reflection.

As can readily be seen, a burst condition at the knee of any of these curves maximizes the ground area subjected to that value of peak overpressure. For example, the area subjected to an overpressure of about 1 psi from a burst at an HOB of about  $1,500 \text{ feet/kt}^{1/3}$  would be about 3.4 times as large as that from a burst at ground level. No single HOB will do the same for all overpressures; "optimum" burst heights shown on Figure 1 alone range from about  $700 \text{ feet/kt}^{1/3}$  for 12 psi to  $1,500 \text{ feet/kt}^{1/3}$  for 1 psi.

For this report, an HOB of  $800 \text{ feet/kt}^{1/3}$  will be used, principally because it appears to be the best HOB for overpressures of about 5 to 10 psi and produces 2-psi overpressure at a distance of about 90 percent of the maximum. Based on Table 1, Mach stem peak overpressures of about 5 to 10 psi are sufficient to heavily damage or collapse all but the strongest urban buildings, while a large amount of damage will be caused by overpressures as low as 2 psi. Also, a review of Reference 1 indicates that this HOB is low enough to create a well formed Mach stem to produce near-maximum dynamic pressures for most types of

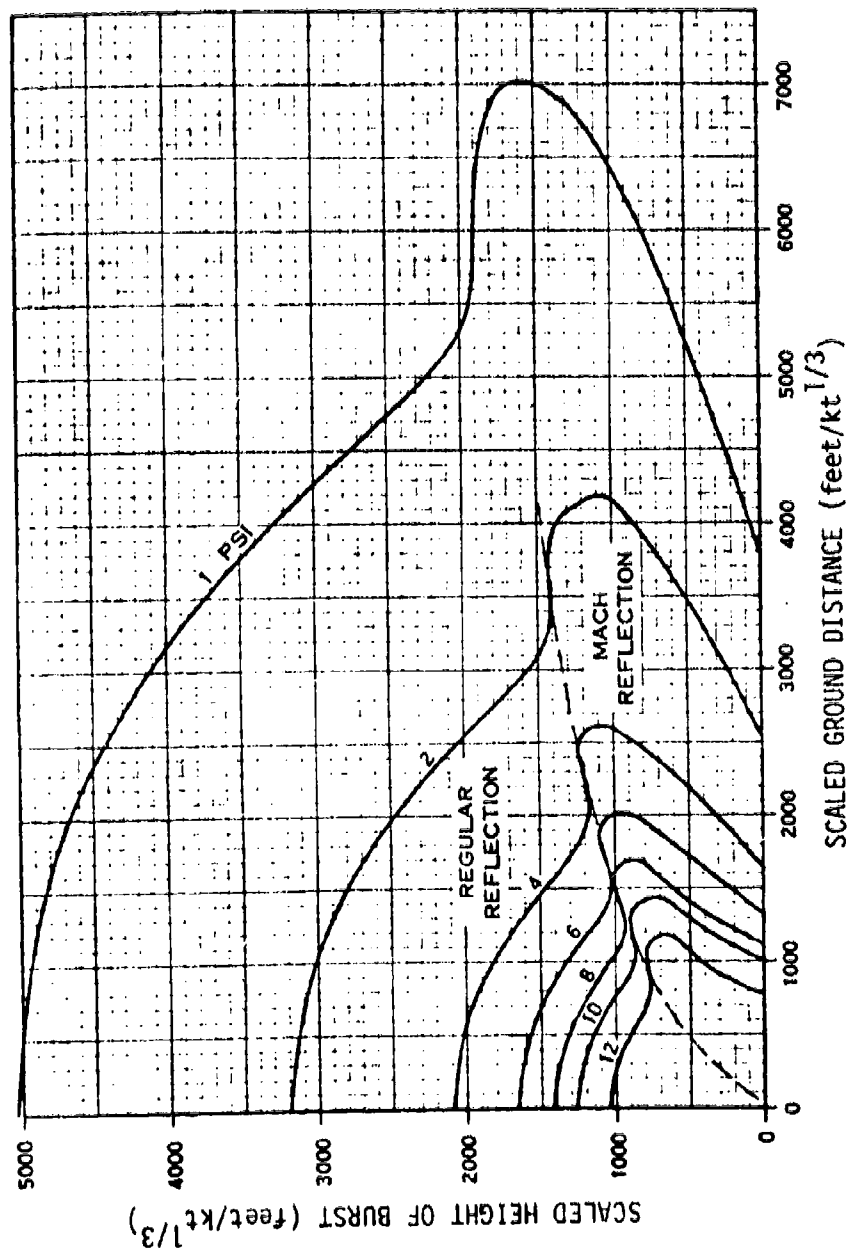


Figure 1. Airblast peak overpressures at the ground surface.  
(Source: Reference 1.)



buildings. The broad conclusions drawn in this report, however, are not especially HOB sensitive; either higher HOBs (for weaker structures) or lower HOBs (for stronger structures) will lead to similar conclusions as long as the structure is subjected to airblast from a well formed Mach stem with flow essentially parallel to the ground and not to the double "incident-reflected" shock combination characteristic of the regular reflection region. In the regular reflection region airflow direction changes, first being toward the ground, then away from it. Some structures at Hiroshima relatively near ground zero survived to show evidence of strong vertical forces, indicating that they were in the regular reflection region.

Since overpressure distances scale as the cube root of the energy yield (at least in the absence of precursors), Figure 1 can be redrawn for a particular scaled HOB to show the dependence of peak overpressure on weapon size and ground range. This is done in Figure 2 for the chosen HOB.

#### AIRBLAST DAMAGE ZONES

The results of Table 1 can be further summarized into damage zones. Table 2 is this author's specification of damage zones to urban areas in general, based on interpretation of Table 1. Based on Table 2, the peak overpressure levels of 2 to 5 psi and 5 to about 10 psi appear to be critical zones. Damage is relatively light or moderate below 2 psi; most residences will be demolished and most high-rise buildings will be stripped of their walls at overpressures between 2 and 5 psi; stronger structures will be heavily damaged at overpressures between 5 and 10 psi; and only the strongest buildings will survive overpressures greater than approximately 10 psi.

Figure 3 is the result of applying Table 2 to Figure 2. Although Figure 3 may be suitable for illustrating airblast damage to urban areas in general, the damage categories are not sensitive enough to illustrate damage to different types of urban areas. For example, residential

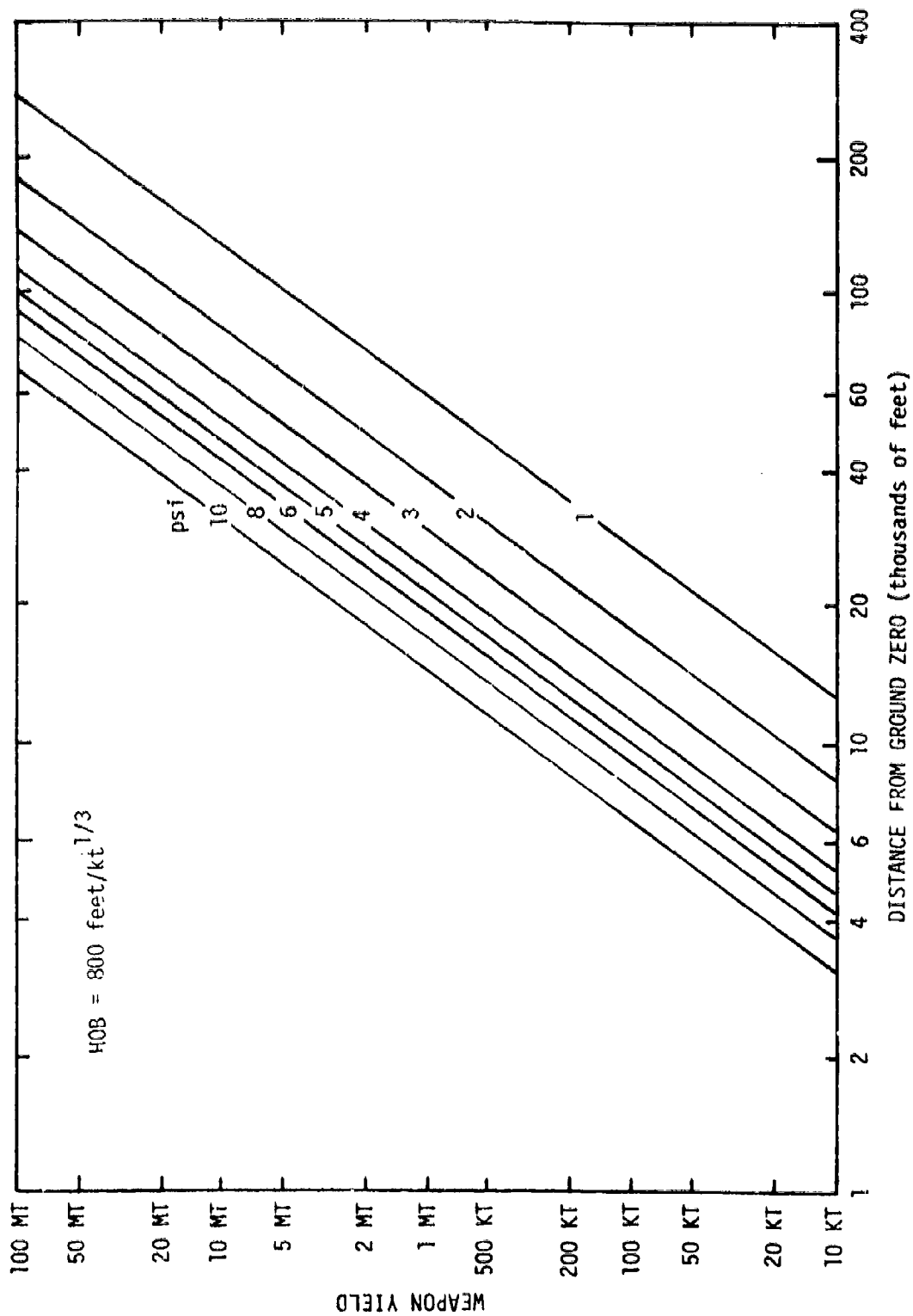


Figure 2. Free-field airblast peak overpressures.

Table 2. Summary of airblast damage to urban areas.

Peak Overpressure	Damage Category	Damage Description
Less than 1 psi	Light damage	Windows and doors will fail and some light interior partitions will be blown down.
1 to 2 psi	Moderate damage	Most light interior partitions will be blown down and building interiors will be severely disrupted. Most light exterior walls facing the blast, including light unreinforced masonry walls, will fail.
2 to 5 psi	Heavy damage	Wood frame buildings and load-bearing masonry walled buildings will be heavily damaged at the lower end of the range and, at the upper end, will be demolished. Most buildings with steel or reinforced concrete frames will be stripped of their walls.
5 to 10 psi	Very heavy damage	Many monumental buildings will collapse. Frames of all but the heaviest steel-frame industrial buildings will collapse. Multi-story steel and reinforced concrete frame buildings with heavy exterior walls will collapse.
10 to 20 psi	Near-complete destruction	The remaining building frames of steel and reinforced concrete will collapse. The remaining stronger monumental buildings will collapse. All but specially designed, blast-resistant buildings will be demolished.

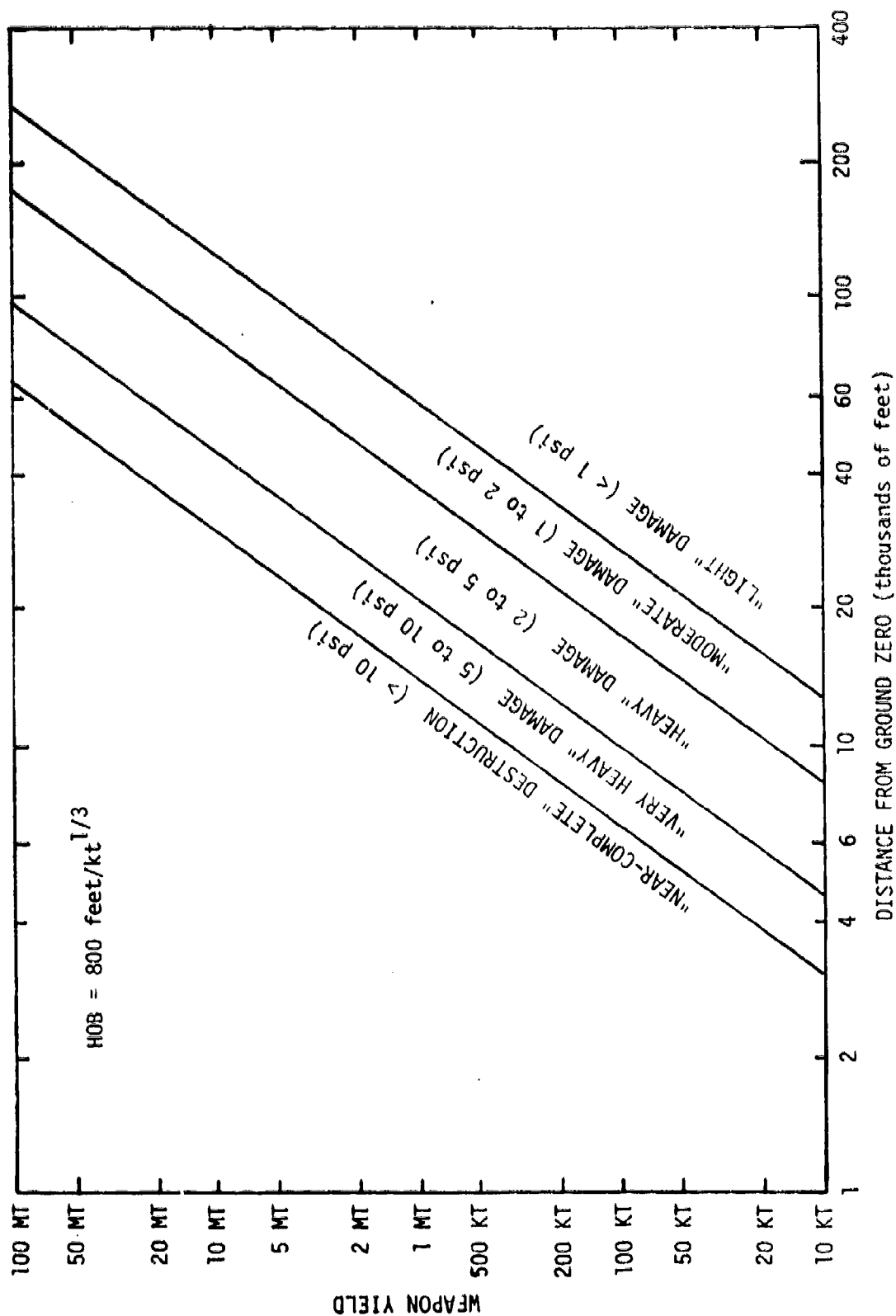


Figure 3. Airblast damage zones in typical urban areas.  
(See Table 2 for description of "light" damage, etc.)

areas will be virtually demolished by overpressures which will only slightly damage many monumental-type buildings. Table 3 is this author's specification of damage zones for single-family residential areas, and Figure 4 is the result of applying Table 3 to Figure 2. A similar process could be followed for other types of urban areas.

Table 3. Summary of airblast damage to single-family residences.

Peak Overpressure	Damage Category	Damage Description
Less than 2 psi	Light damage	Windows, doors, light interior partitions, and light masonry walls will fail, but the structural integrity of most residences will not be endangered. Roofs and building frames, and load-bearing walls will suffer only superficial damage.
2 to 3 psi	Moderate damage	Building interiors will be severely disrupted and walls and roofs of some residences will fail or be damaged to the point of collapse.
3 to 5 psi	Heavy damage	Most single-family residences will collapse. Only the strongest residences will survive overpressures greater than 5 psi.
Greater than 5 psi	Near-complete destruction	Virtually all single-family residences will be collapsed.

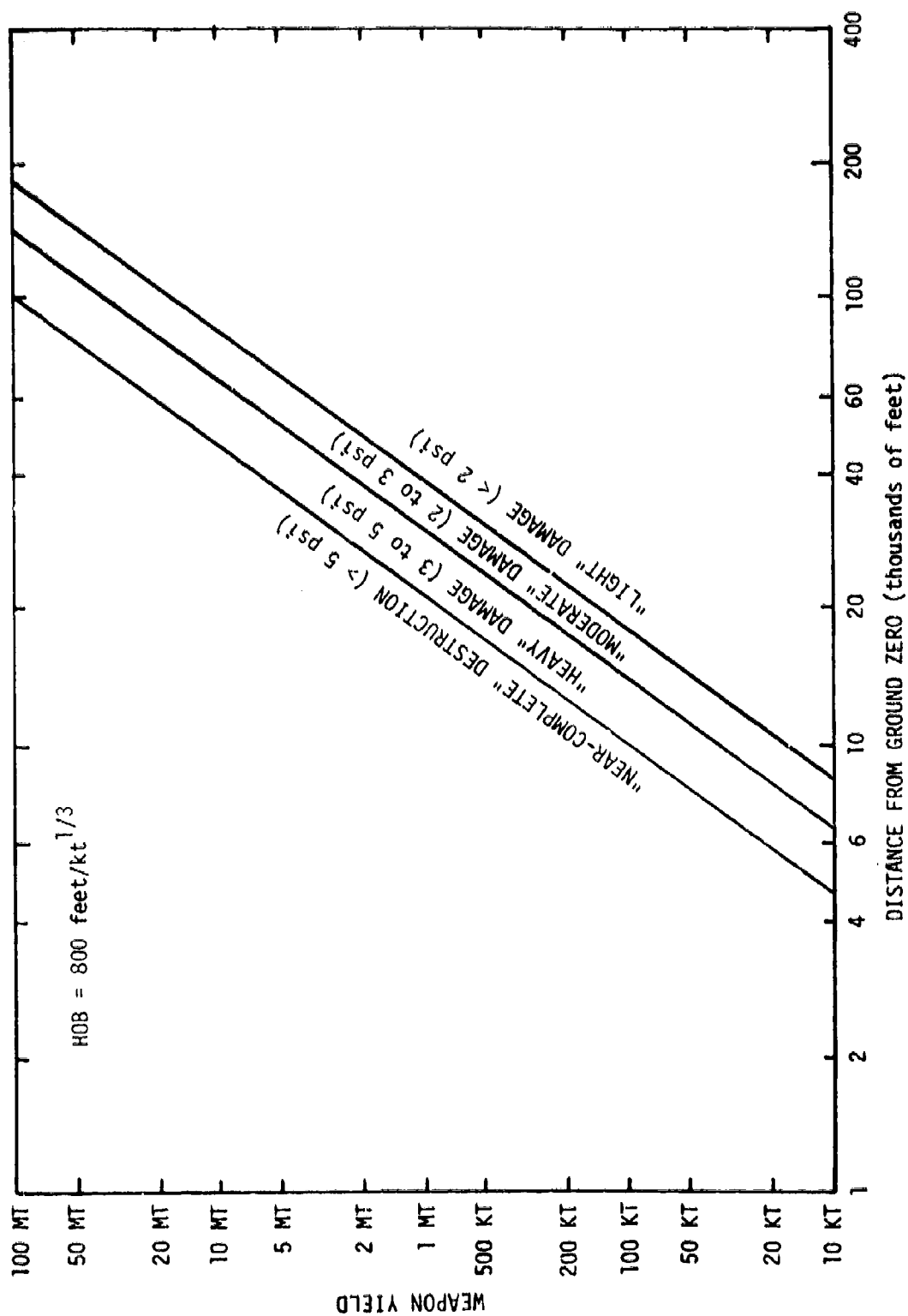


Figure 4. Airblast damage zones in single-family residential areas.  
(See Table 3 for description of damage zones.)

### SECTION 3

#### THERMAL RADIATION ENVIRONMENT AND EFFECTS

The effects of thermal radiation and the resulting fires in urban areas are analyzed in this section without considering the effects of airblast which may modify the thermal effects. The synergistic effects of airblast and thermal radiation and fires are addressed in Section 4.

#### THERMAL RADIATION PHENOMENA

A large proportion of energy from a nuclear airburst is liberated as a short pulse\* of thermal radiation which propagates radially from the nuclear fireball at the speed of light, far faster than the airblast wave. As it passes through the air, the intensity of the thermal pulse is attenuated at a rate dependent, though not strongly so, on the clarity of the air. It is scattered by clouds or fog, and either scattered or absorbed by smoke, depending on the constituents of the smoke.

The "free-field" (no opaque obstructions within line-of-sight of the fireball) "radiant exposure" (total amount of thermal radiation per unit area) on the ground is a complex function of the weapon yield, HOB, distance to the burst, and properties of the atmosphere. Reference 1 presents parametric relationships and describes a procedure from which values of radiant exposure can be calculated for given sets of conditions. For the chosen HOB of 800 feet/kt<sup>1/3</sup> and generally "clear" visibilities of 16 miles\*\*, Figure 5 gives values of

---

\* Actually, the effective thermal pulse is preceded by an initial pulse of very short duration. The duration of the effective thermal pulse from a low airburst varies from approximately 1 second for a 10-kt burst to 30 seconds for a 10-MT burst.

\*\* Within broad limits, the amount of thermal radiation received at some distance from a low airburst, on a generally clear day is not strongly affected by atmospheric visibility. At distances one-half the visual range, a variation of only about 35 percent occurs for visibilities ranging from 10 to 50 miles (Reference 2).

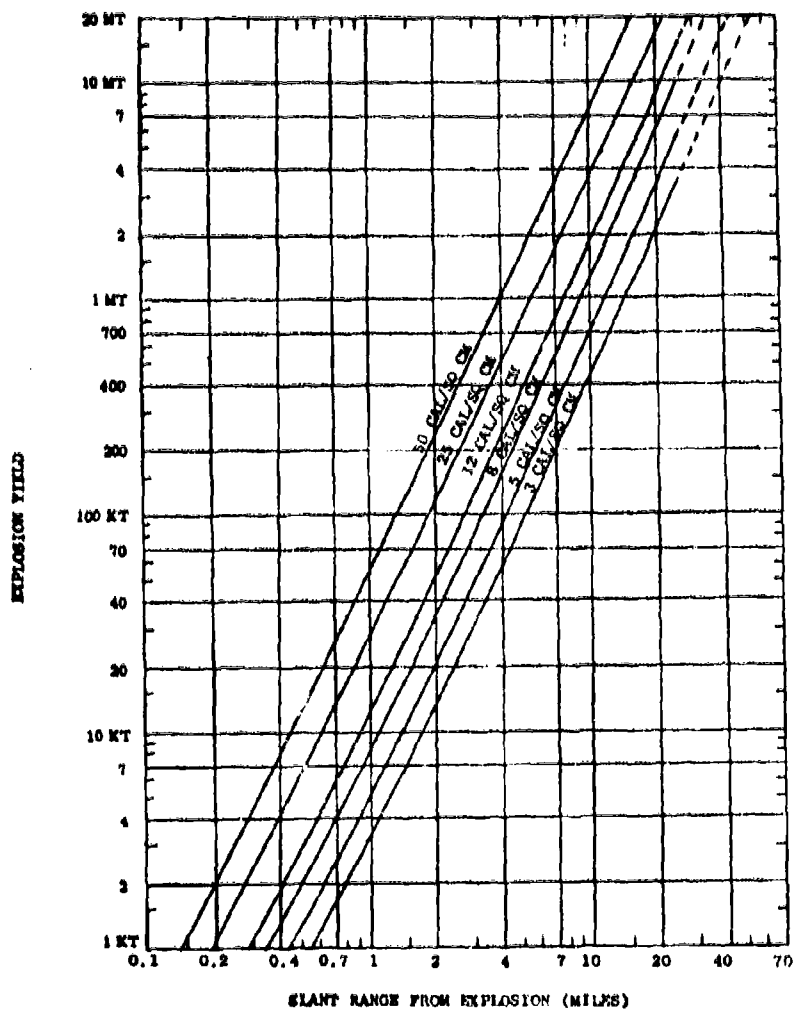


Figure 5. Slant ranges for specified radiant exposures as a function of energy yield of an explosion at moderate altitude (less than 20 miles) for 50-mile visibility.  
(Source: Reference 2.)



radiant exposures in calories per square centimeter ( $\text{cal/cm}^2$ ) which correspond very closely with those calculated by the detailed method of Reference 1.

An object can be shielded from thermal radiation by interposing an opaque material between it and the radiation source. (Airblast passes around solid objects, and airblast shielding of one object by another is far less effective than thermal radiation shielding.) In the absence of thermal shielding, opaque objects such as buildings, furniture and clothing will partly absorb and partly reflect the thermal energy incident on them. The energy absorbed raises the near-surface temperature of the objects and if enough is absorbed, can ignite combustible materials. A given combustible material will ignite at a certain average level of radiant exposure called the "critical ignition exposure" (CIE). Different samples of the same type of material will have different CIEs, depending on (1) the characteristics of the material, primarily thickness, color, and moisture content (thin, dark-colored, or dry materials ignite much easier than thick, light-colored, or damp materials) and (2) the rate of delivery of the thermal energy which is a function of the weapon yield.

Short thermal pulses from low-yield weapons appear to be more "efficient" in igniting materials than the much longer pulses from large-yield weapons, in that the short pulses require a smaller total energy to ignite a given material than do the long pulses. This conclusion can be misleading however. For example, if  $25 \text{ cal/cm}^2$  is the CIE of a particular material exposed to thermal radiation from a 1-MT burst, approximately  $50 \text{ cal/cm}^2$  would be required to reach the CIE of the same material when exposed to thermal radiation from a 20-MT burst. Nevertheless, as shown in Figure 5, a 20-MT weapon produces the higher required level of thermal energy at approximately twice the range as for a 1-MT weapon. Thus, increasing the yield of a weapon increases the distance at which a given level of thermal damage can occur.

## INDEX OF THERMAL DAMAGE

The information in Figure 5 can be used to display thermal damage zones by use of an index which directly relates radiant exposure to the CIE of materials for various weapon yields.

The majority of interior materials which may be ignited when exposed to nuclear thermal radiation are types of cellulose (Reference 3). The CIEs of various building and household materials of interest are shown in Figure 6. It can be seen that the CIEs of most materials vary with weapon yield roughly in the same manner as does newspaper, although dark cotton and rayon, two of the commonest household materials (Reference 13), appear to deviate most from this relationship. As indicated in References 1 and 3, the CIE of newspaper has been used in the past as an index of fire potential. Therefore, the CIE of dark-printed newspaper text (line #2 in Figure 6) has been chosen as the index of thermal damage in this study. The CIEs of other materials can be expressed as a multiple of the CIE of dark-printed newspaper text.

Figure 7, based on Figure 6 and radiant exposure calculations from Reference 1 (similar in value to those shown in Figure 5), shows radiant exposures in the form of multiples of the CIE of dark-text newspaper as a function of weapon yield and ground distance from ground zero. Because such multiples can be broadly related to CIEs of a wide variety of materials, it is assumed that all weapon-yield/ground-range combinations on the same line correspond to equal thermal damage, i.e., the lines are "isodamage" lines.

## THERMAL RADIATION EFFECTS ON URBAN AREAS

The incendiary effects of nuclear weapons on urban areas have been a subject of concern for years. Numerous studies and experiments have been conducted regarding ignition of combustible materials (fuels), sustained burning and spread of fires within structures, and spread of fire between structures. [The Role of Fire in Nuclear Warfare (Reference 3) summarizes the state-of-the-art in this area and indicates the complexity of the problem.] It is exceedingly difficult, if not impossible, to

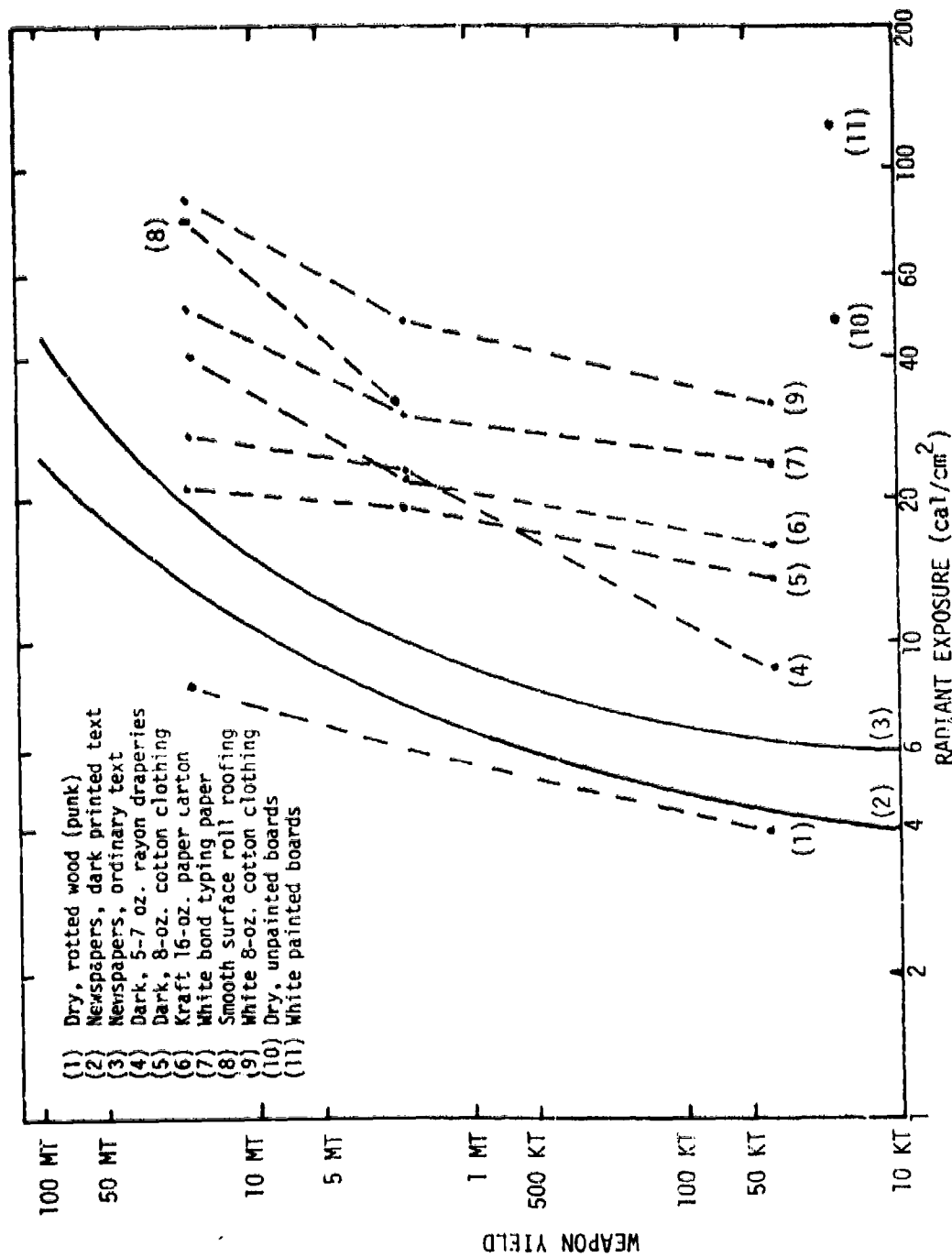


Figure 6. Critical ignition exposures (CIE) of common household and construction materials. (Based on information in References 1 and 4.)

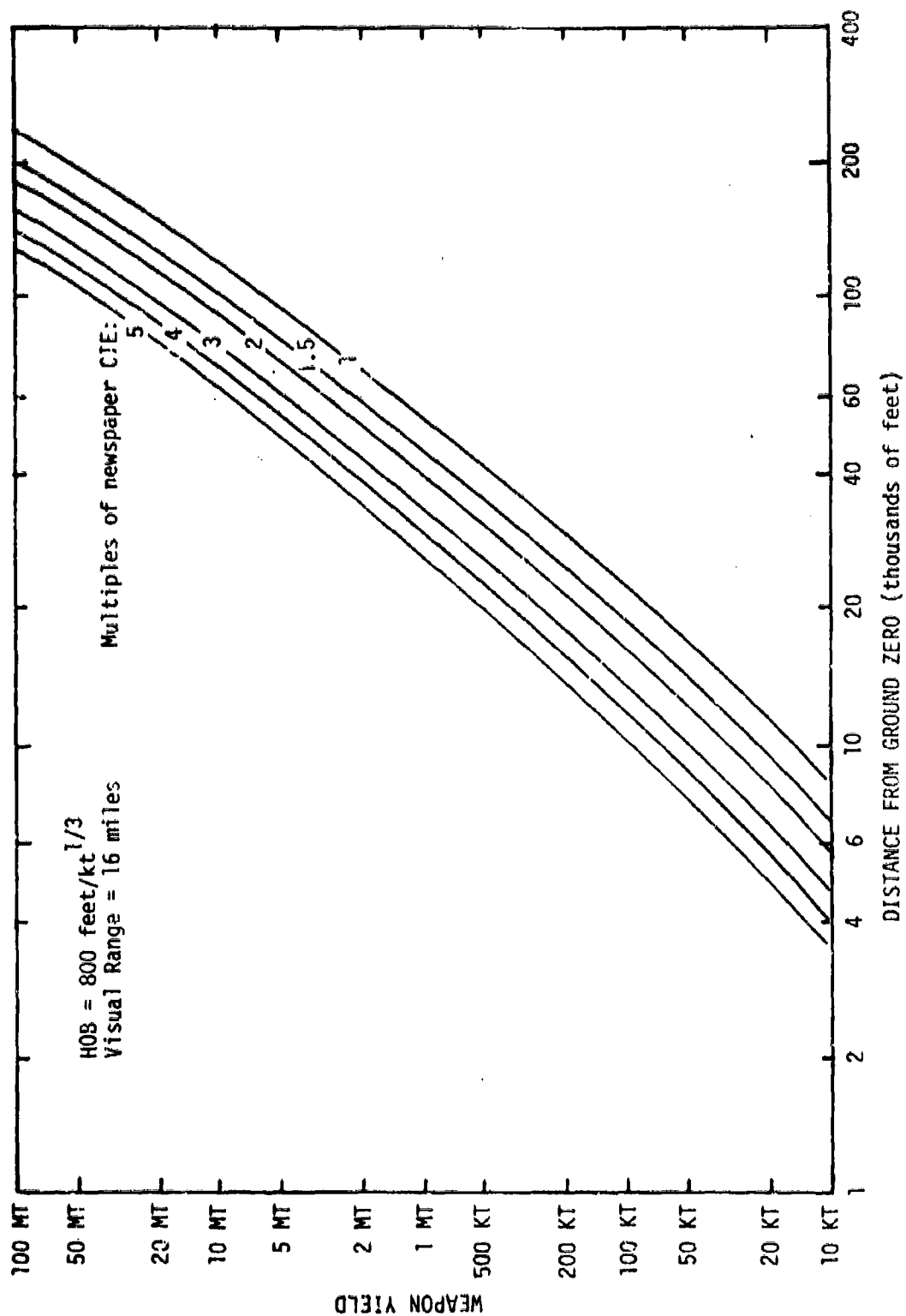


Figure 7. Free-field radiant energy as multiples of the CIE of dark-text newspaper.

quantify and generalize the results of such studies so that the results can be applied to predict, with accuracy and confidence, the initial and ultimate thermal effect of a nuclear weapon on a city under a particular set of circumstances. Comprehensive models have been developed by both IITRI and URS, but these are much too detailed for the purposes of this study. (Also, for certain conditions, they appear to lead to inconsistent results.)

As with airblast damage, however, certain broad conclusions can be drawn from earlier studies of the fire problem that can lead to a relatively simple prediction technique.

Before proceeding further, the influence of the chosen HOB on thermal effects should be analyzed. Nuclear thermal effects usually become significant at distances where the free-field thermal energy is one to two times the CIE of dark-text newspaper provided (in the absence of strong atmospheric scattering of thermal energy) the HOB is high enough to expose a sufficient fraction of windows to full view of the fireball. Under the assumptions of Figure 7 (an HOB of  $800 \text{ feet/kt}^{1/3}$  and "clear" atmospheric conditions), the elevation angles of a 30-MT, 1-MT and 10-kt burst are  $9.5^\circ$ ,  $10^\circ$  and  $14.5^\circ$ , respectively, at distances where the free-field thermal energy is 1.5 times the CIE of dark-text newspaper. Based on Figure 8 (a plot of calculations by SRI to determine the probability of exposure of interior fuels as a function of elevation angle to the detonation point, assuming specific window and room dimensions and equal distribution of interior fuels in a horizontal plane two feet above the floor), the chosen HCB is near the optimum for exposing interior fuels to thermal radiation from low-kiloton weapons, and the probability of exposure is not greatly below optimum for megaton weapons. Therefore, although the HOB of  $800 \text{ feet/kt}^{1/3}$  was chosen for maximum airblast effect, it is also a reasonably good choice from the standpoint of maximizing thermal effects.

One method of estimating nuclear thermal effects in urban areas basically involves two key steps: (1) relating free-field thermal radiation levels (from Figure 7) to the percentage of structures which

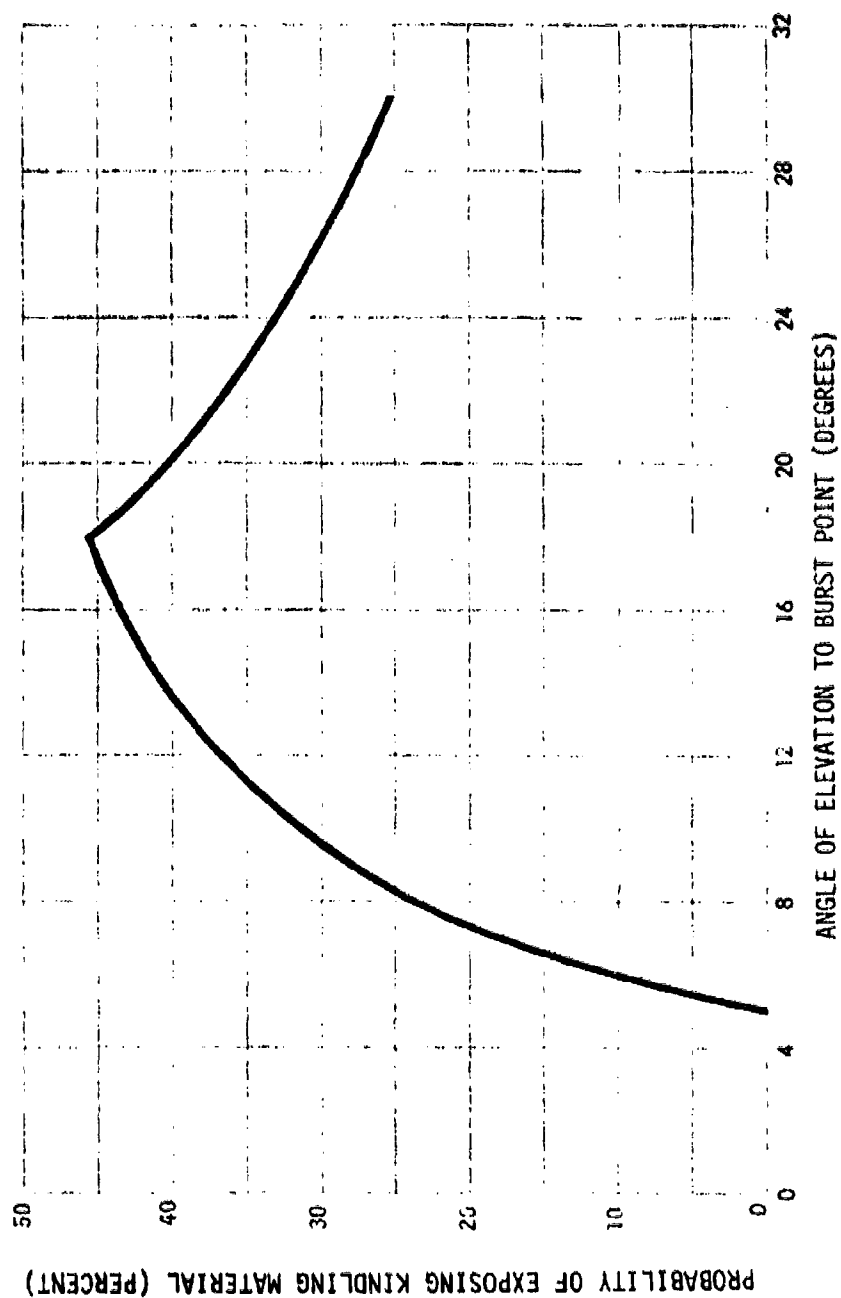


Figure 8. Probability of exposing kindling materials in a compartment as a function of angle of elevation to burst point.  
(Source: Reference 11.)

are likely to burn as a result of the initial ignition of interior fuels, and (2) estimating the degree to which an area is burned out as a function of the percentage of structures which are initially ignited.\*

Among the detailed studies that have been made of the effects of nuclear weapons on urban areas was one sponsored by what is now the Defensive Civil Preparedness Agency (DCPA) known as the Five-City Study. In this study the cities of Boston, Detroit, Albuquerque, San Jose and Providence were assumed to be the subjects of attack with megaton-range weapons, the burst conditions of which were strictly specified (even to the hour and minute of the day). Areas of these cities were surveyed in detail and many effects of these attacks were studied. The detailed analyses related to San Jose are particularly germane to this report because the assumed atmospheric conditions and HOB conform closely to those used in this report and a relatively large amount of survey and analyzed data have been published.

Figure 9 summarizes the results that apply to single-family residences in San Jose, and shows that there would be a large proportion of significant residential fires at distances where airblast damage would be expected to be light to moderate. Figure 10 shows the results of applying the URS fire model to the Five-City data for single-family residential areas in San Jose. The fraction of residences having significant initial ignitions as a function of distance shown in Figure 10 corresponds closely with the probabilities of a significant fire in a single-family residence shown in Figure 9.

It is of particular interest that Figure 9 shows the relationship of the free-field radiant exposure, the CIE of newspaper (dark-printed text), and the probability of a significant fire in a single-family residence and that Figure 10 relates the fraction of homes initially ignited

---

\* The remainder of this report is restricted to analysis of single-family residential areas. Results of previous studies have not been found which could be applied to other types of urban areas; but if and when such results are available, such urban areas can be analyzed by the technique described in this report.

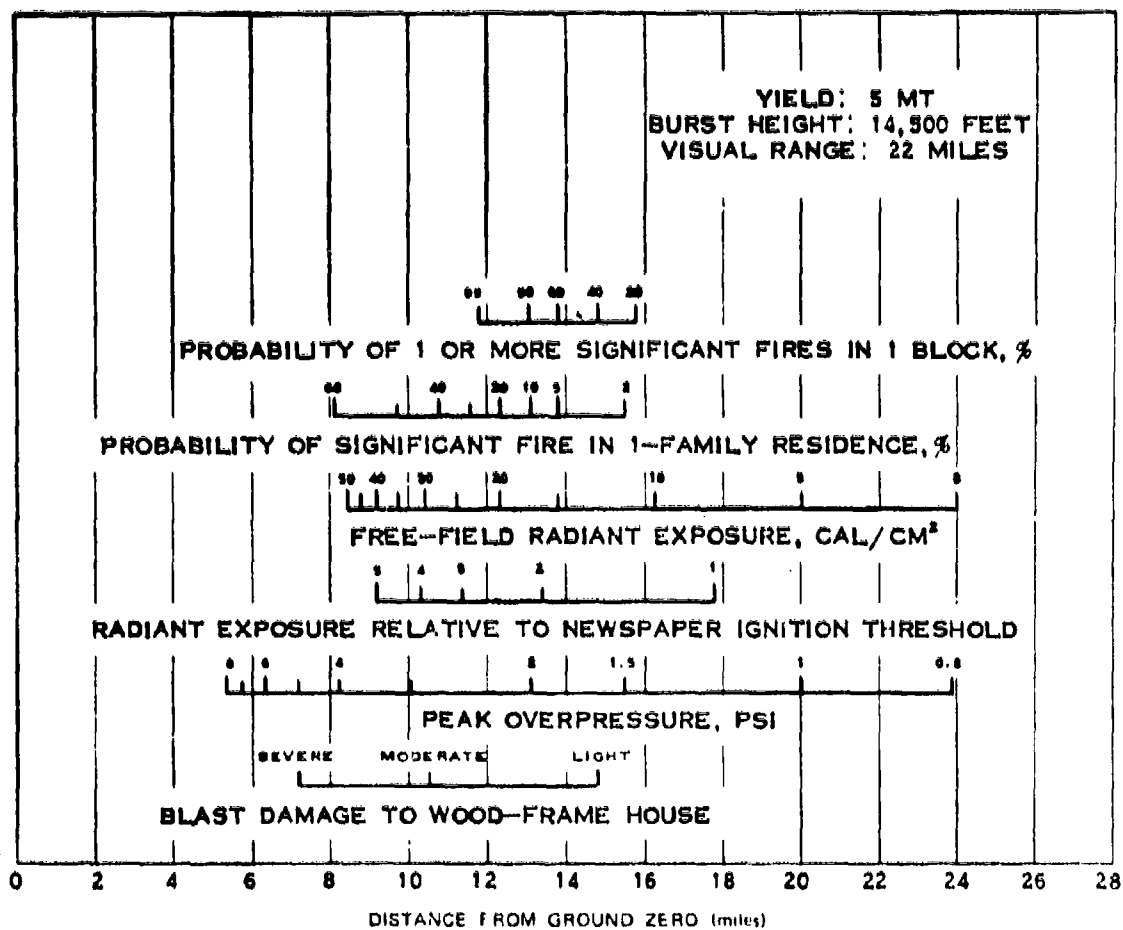
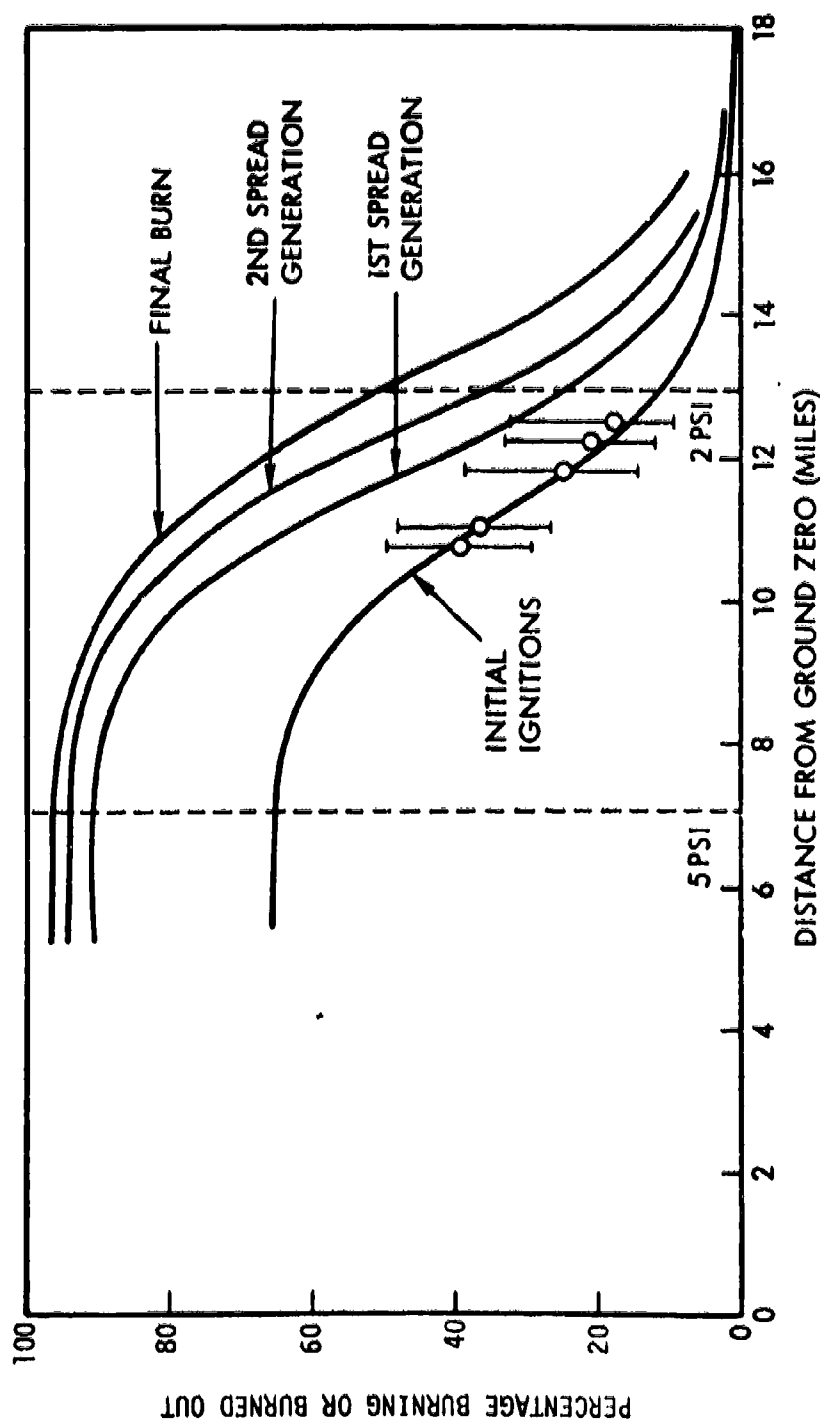


Figure 9. Summary of predicted damage to San Jose, California, in a nuclear attack.  
(Source: Five-City Study; Reference 1.)





NOTE: The data points shown are the result of field surveys and the vertical bars are the standard deviations of the data values. It is assumed that this figure is based on initial ignitions due to line-of-sight exposure of interior fuels to the nuclear fireball and fire spread only by radiation or convection.

Figure 10. Fraction of single-family residences in San Jose burning or burned-out as a function of distance from ground zero and time (in spread generations) following attack.  
(Source: Five-City Study; Reference 12).)

to those finally burned up.\* Although these results are based only on residences and burst conditions in San Jose, these relationships should apply in general to other single-family residential areas under generally clear atmospheric conditions and HOBs in the vicinity of  $800 \text{ foot/kt}^{1/3}$ . The solid lines in Figure 11 are a plot of the relationships shown in Figures 9 and 10 in terms of the chosen index of fire potential, the CIE of dark-text newspaper. The "final burn" line of Figure 11 was then used along with Figure 7, to construct Figure 12 which shows thermal damage levels for single-family residential areas in terms of percentage of houses burned up as a function of weapon yield and distance from ground zero.

Relationships between initial ignitions and final burn other than those of Figure 10 and relationships between fireball thermal radiation and the probability of a significant fire other than those of Figure 9, could be used to estimate thermal damage levels, if circumstances so warrant. For example, if a high potential for fire spread is assumed (e.g., a windy day), only 20 percent of initial fire starts (rather than about 50 percent) might be sufficient to assure 90 percent burnout. In this case, Figure 11 indicates that the critical level is about 2.5 times the CIE of newspaper, and Figure 7 can then be used to find the yield/distance combinations that correspond to 90 percent burnout.

Similarly, if the number of initial fire starts differs significantly from that given in Figures 9 or 10 (which could occur for a number of reasons, e.g., a different fuel density in a different city, early fire

---

\* The top line of Figure 9 shows the probability of one or more significant fires in a hypothetical block of 20 houses, based on the probability of a significant fire in a residence. However, this does not indicate the overall fire hazard. A block may contain one or more significant fires, but unless the probability of fire spread is sufficiently high, only a small fraction of houses may be burned out. Also, "finally burned" in this report includes only houses involved in the first few fire-spread generations and does not include houses burned up as a result of the subsequent movement of mass fires.

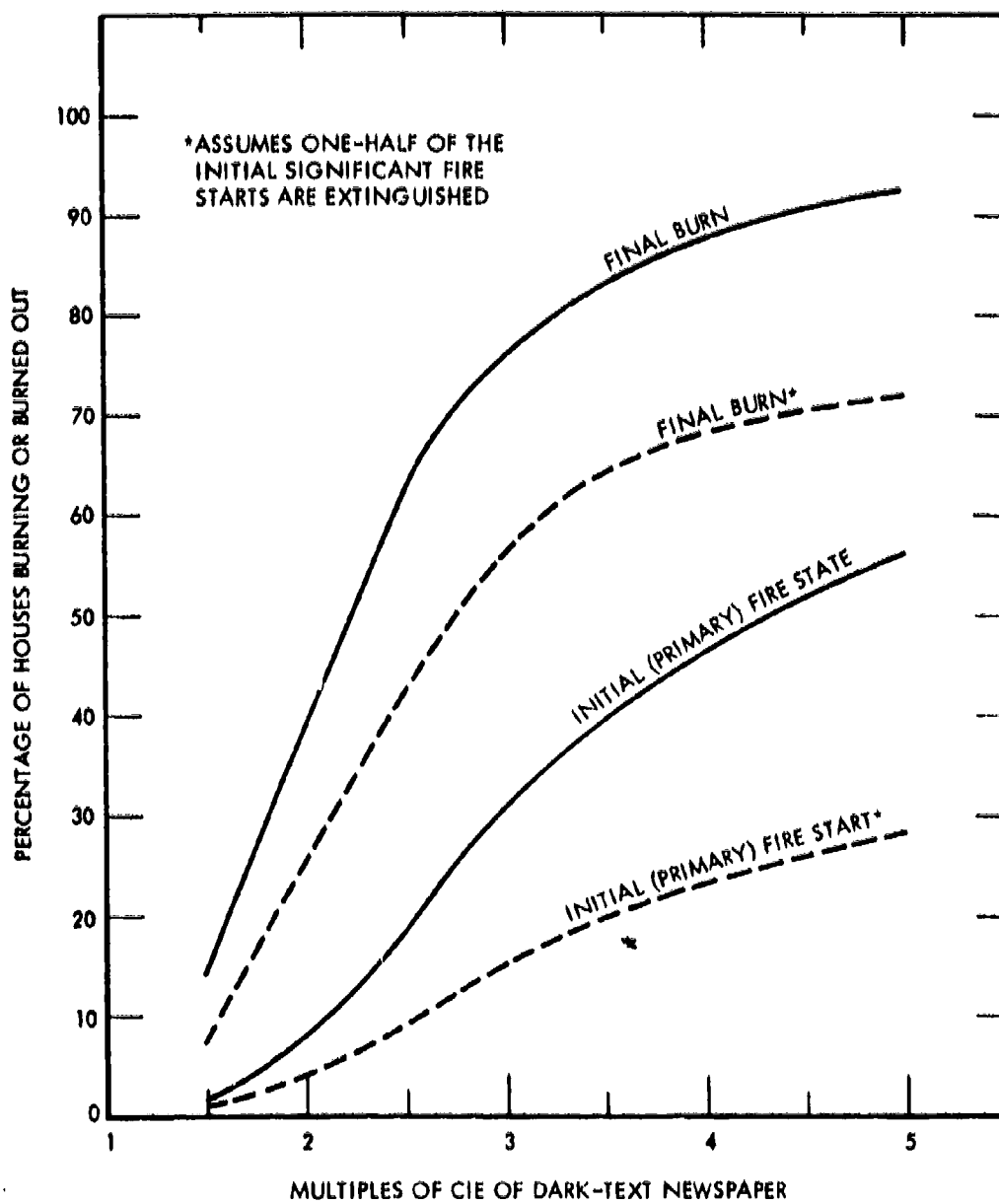


Figure 11. Fraction of single-family residences initially ignited and finally burned up. (Based on data from San Jose Five-City Study as shown in Figures 9 and 10.)

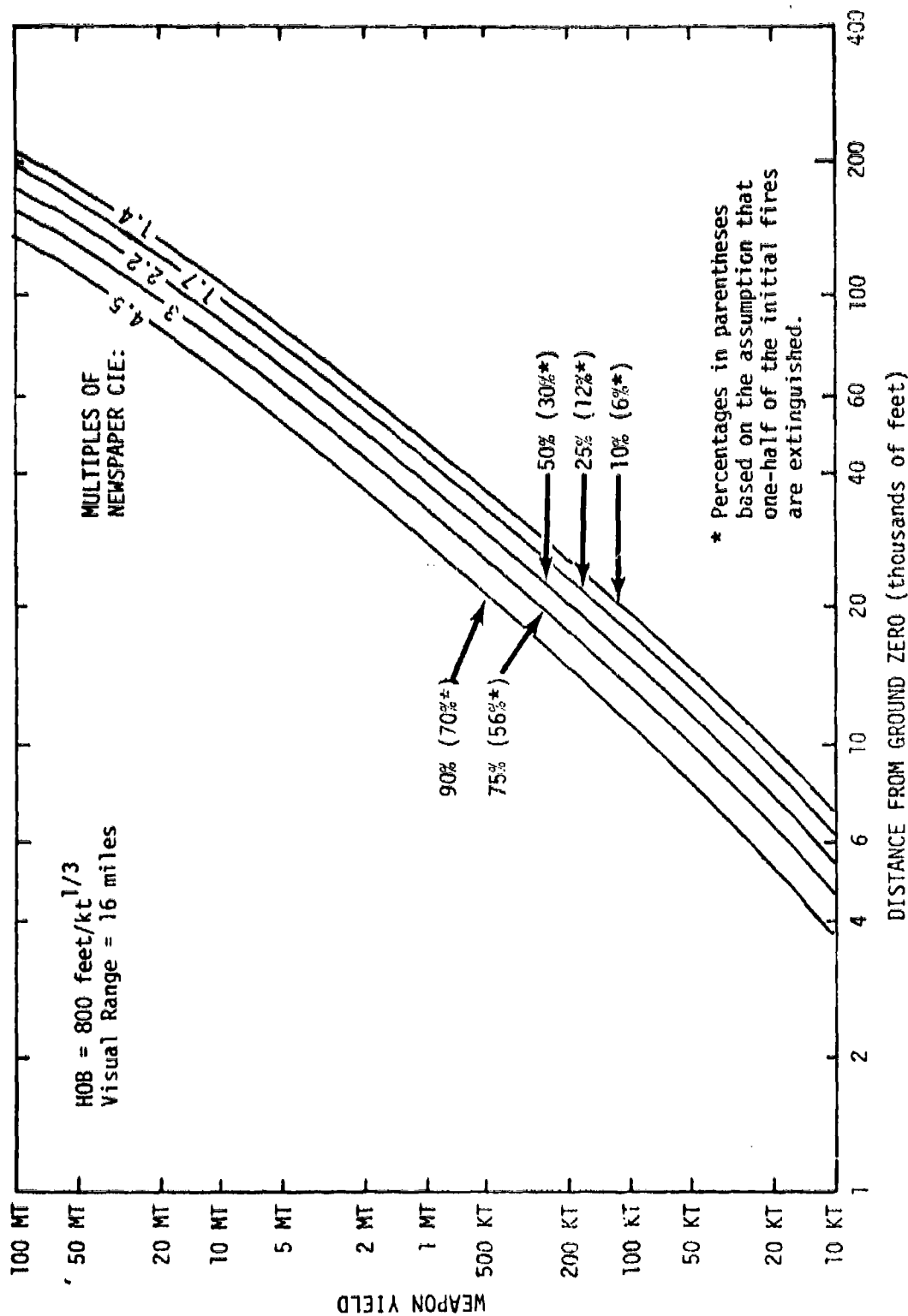


Figure 12. Percentage of single-family residences finally burned up.  
(Based on data from San Jose Five-City Study as shown in Figure 11.)

fighting efforts) the relationship between initial fire starts and final burn shown in Figure 11 (derived from Figure 10) can be used to determine the effect of the change. If it is assumed, for example, that the number of significant initial fire starts is reduced by a factor of two (shown as the lower dashed line in Figure 11), and that the relationship between initial fire starts and total burn is maintained (e.g., 10 percent initial fire starts always produces 48 percent total burn whether the 10 percent is the total initial ignitions or is the result of extinguishing one-half of the initial ignitions which otherwise would have resulted in 20 percent initial fire starts), the final burn would be as shown by the upper dashed line of Figure 11.

It can be seen that the two-fold decrease in initial fire starts significantly reduces the fire damage, whether viewed as a reduction in the percentage of houses finally burned up at a given range from ground zero or viewed as a decrease in the area subjected to a given level of thermal damage. For example, at a distance where the free-field thermal radiation is 2.2 times the CIE of newspaper, the fraction of houses finally burned up is reduced from approximately 50 percent to approximately 35 percent (a reduction of 30 percent). The 50 percent burnout level now occurs where the free-field thermal energy is approximately 2.7 times the CIE of newspaper, which corresponds to a reduction in range of approximately 10 percent to 15 percent and a reduction in area of approximately 20 percent to 30 percent. Similarly, the 90 percent burnout level would be reduced to approximately 70 percent, a reduction of 22 percent. Note that now there is no 90 percent total burnout range; the maximum burnout achieved, as shown in Figure 11, is slightly greater than 70 percent.

The percentages shown in parentheses in Figure 12 are the percentage of houses finally burned up assuming one-half of the initial fire starts are extinguished. Under this assumption, each of the iso-damage lines now corresponds to a smaller percentage of houses finally burned up.

## SECTION 4

### COMBINED AIRBLAST AND THERMAL DAMAGE

The nuclear weapon airblast and thermal radiation environments and effects on buildings have been summarized independently in Sections 2 and 3. Figure 13 is a direct overlay of Figures 4 and 12 and illustrates the relative importance of airblast and thermal effects on single-family residential areas without considering synergistic effects.

Figure 13 suggests that, for weapon yields greater than about 50 kt, thermal damage at particular ranges tends to be more severe than airblast damage. With a weapon yield of 1 MT, for example, at a range of about 38,000 feet airblast damage would be characterized as light to moderate while thermal damage would lead to burnout of 50 percent of houses (which subjectively, seems more severe). Similarly, at a range of about 33,000 feet airblast damage would be characterized as moderate while thermal damage would result in a 75 percent burnout. Finally, at a range of about 28,000 feet airblast damage would be characterized as moderate to heavy, while thermal damage would result in some 90 percent of houses burning up, essentially a complete burnout. Had the parenthetical percentages of Figure 12 been used, the same general conclusions would be drawn from Figure 13 except, of course, that the moderate to heavy airblast damage would have to be compared with a 70 percent final burn.

In other areas with higher fire spread potential (areas of multi-family dwellings, for example), the potential for thermal damage (were there no blast effects) would be even greater than the potential for airblast damage (were there no thermal effects).

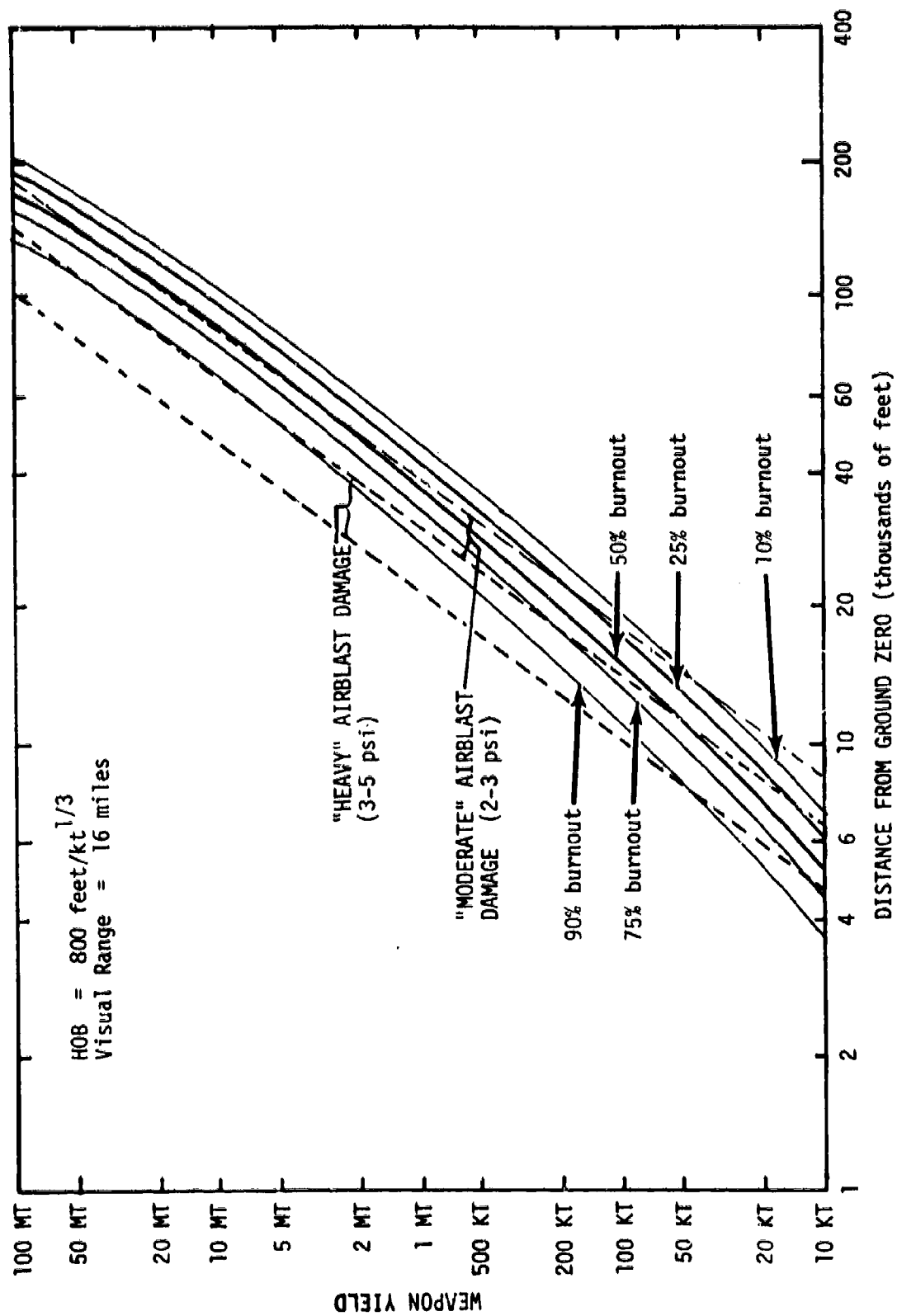


Figure 13. Airblast and thermal damage levels assuming no synergistic effects (single-family residential areas).

## INFLUENCE OF THERMAL RADIATION ON AIRBLAST DAMAGE

The thermal pulse from a nuclear weapon precedes the airblast and, under certain conditions, can create a precursor to the airblast shock front. Sudden heating of heat-absorbing ground surfaces, such as asphalt or dusty surfaces, can cause vaporization of volatile materials and throwing of hot particles into the air above the ground surface. The airblast shock front propagates faster through this heated layer of air, causing the airblast overpressure to rise less sharply and to reach a lower peak value than would be expected for "near-ideal" conditions. At increasing distances from ground zero the effects of a precursor are diminished.

Although precursors are not well understood, the available information from Reference 1 indicates that:

1. For a scaled HOB of approximately 650 to 800 feet/kt<sup>1/3</sup>, an airblast precursor may form if a "nonideal" thermal surface (particularly asphalt) exists; but a precursor should not form for an HOB greater than 800 feet/kt<sup>1/3</sup> (the height of burst used in this study).
2. If a precursor is formed, it dissipates at a ground distance where the peak overpressure is approximately 8 to 10 psi. Beyond this distance the airblast reverts to near-classical shape.

Also, the ground surface of urban areas is broken up by buildings and covered with large amounts of heat reflecting surfaces such as concrete, which should inhibit the formation of a precursor.

For the above reasons, a precursor is not expected to exist for conditions of interest in this study, i.e., an HOB of 800 feet/kt<sup>1/3</sup>, an overpressure range of interest which is primarily beyond the range of a possible precursor, and "near-ideal" ground-surface thermal conditions typical of urban areas.



Although the surfaces of buildings will be heated and may ignite, it does not seem that buildings should be significantly weakened by fire due to the effects of thermal radiation during the relatively short time period between arrival of the thermal pulse and airblast. For a nuclear weapon in the range of 1 to 30 megatons, the thermal pulse arrives at, for example, the 2-psi overpressure range only 30 to 90 seconds ahead of the airblast. For a lower-yield weapon this time interval is even shorter.

In summary, for the conditions of interest in this report, the thermal pulse from a nuclear weapon should not significantly modify the airblast environment or effects of the airblast.

#### INFLUENCE OF AIRBLAST ON DAMAGE BY FIRES

Under some conditions, airblast can have a direct effect on fire damage by modifying the number of initial fire starts. Airblast also can have more indirect effects on fire damage by creating airblast damage which may affect the spread of fires and the ability to fight fires.

#### Extinguishment of Primary Fires by Airblast

There have been only two programs specifically designed to study the effect of airblast on fires, although it was observed during field tests that airblast appeared to affect "primary ignitions" (fires caused by the thermal pulse from a nuclear weapon). The first specific work in the area was done by Tramontini and Dahl (Reference 14) in 1953 using small quantities of forest kindling fuels and an impulsive air shockwave created by bursting a diaphragm sealing a pressurized tank. While they observed that shockwaves were less effective in extinguishing fires in material that smoulders (like punk, which sometimes bursts into flame well after passage of the wave), they also found that fires in lighter materials (weathered ponderosa pine needles, madrone leaves, cheat grass, crumpled newspapers) were completely extinguished by passage of the wave. Though somewhat difficult to

interpret because their flow conditions well behind the shock front differed from those behind classical shockwaves, their results suggested that relatively high overpressure shockwaves (generally greater than 5 psi) would be required to put out most fires.

The conditions of their tests were so different from those in urban areas, however, that the effect of airblast on urban area fires started by the thermal pulse of a nuclear weapon was a matter of controversy for many years. In 1970, Goodale attacked the problem directly by carrying out a test program under conditions much closer to those in an urban area subjected to a nuclear attack (Reference 10). Tests were conducted in a shock tunnel with a test section large enough (8.5 x 12 feet) that a full-sized room could be installed, and the room could be furnished with real furniture. It was configured in a number of ways (as an office, a living room and a bedroom). The contents were ignited as they might be from a thermal pulse, and one of the room's walls, designed not to collapse and equipped with a window opening, was struck by shockwaves of approximately 1.1, 2.4 and 4.9 psi peak incident overpressures. Both large and small window openings (51% and 14.4% of the wall area) were used.

Far more movement of the room contents occurred with the small window opening than with the large opening\*, but Goodale found (for both window openings) that shockwaves with incident overpressures of 2.4 and 4.9 psi extinguished all flames; shockwaves with incident overpressures of about 1.1 psi did not. Thus, at a threshold level somewhere between 1.1 and 2.4 psi, airblast waves become very efficient extinguishers of primary ignitions, although the Tramontini and Dahl findings that smouldering fires frequently reignited were confirmed.

---

\* In both cases, the shockwave reflects from the wall, and the reservoir of hot high-pressure air caused by the reflection generates a strong flow, or jet, through the opening. With the small opening, pressure due to the reflection process stayed higher for a longer period of time. With the large opening more than half the shockwave simply passed through the opening into the room.

Goodale also studied the effects of his findings on the probability of generating sustaining primary fires, assuming that overpressures above 2 psi extinguished flaming combustion while overpressures below 2 psi did not extinguish flames. His results for residential occupancy, plotted as a function of peak overpressure, are shown in Figure 14. (Commercial and industrial occupancies were similarly examined.) Note on Figure 14 that with windows uncovered, at overpressures above about 2 psi, the airblast strongly affects the probability of sustained fires, reducing it over most of the range by about a factor of 2.

The plotted effects for covered windows appear to be even more spectacular, with decreases of probability by a factor of 3 or more at higher overpressures and no fires predicted for overpressures of 2 to 4 psi. This occurred principally because, at the time of these tests, Goodale's model of fire generation from burning curtains (without considering the capability of a blast wave to extinguish the fires), assumed that the burning curtains would be flung into the room upon arrival of the blast wave. In a subsequent (1971) study, however, he found that the conditions for this to happen were very critically dependent on the burning time of the curtains and the time of airblast arrival (Reference 15). If the blast arrived too late, the curtains would already have burned through and dropped to the floor. The blast wave would not deposit them on furniture in the room, and thus cause fires. The time during which ignited curtains could cause fires by being transported into the room (either burning or smoldering) was brief enough that Goodale suggested it would be misleading to depend on an increase in the probability of room fire due to curtain fire if only blast transport, not blast extinguishment, were taken into account.

Goodale's results were incorporated in the IITRI fire model along with other modifications to update the code (Reference 16). The modified code indicated that primary fires would be reduced by a factor as large as 5, with most of the reduction caused by airblast blowout of primary ignitions.

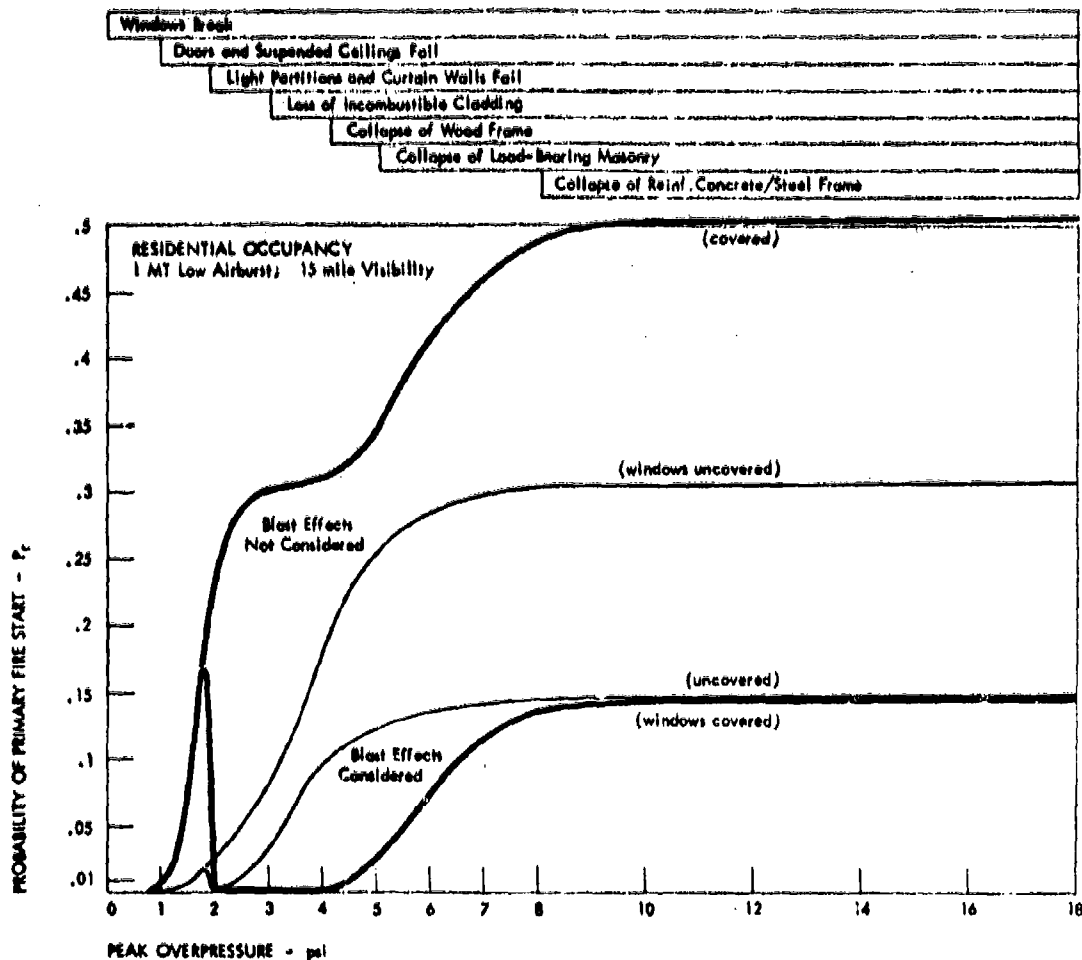


Figure 14. Probability of primary fire starts in urban interiors, as a function of overpressure, residential occupancy.  
(Source: Reference 10.)

Figure 15, derived from the solid lines of Figure 11, shows the reduction in the fraction of residences finally burned up assuming that airblast greater than 2 psi peak overpressure blows out enough initial ignitions to reduce by a factor of 3 the number of residences which would otherwise initially burn. (Note that high-yield weapons do not reduce fire starts as much as lower-yield weapons. This is because higher-yield weapons produce a larger fraction of initial ignitions beyond the 2-psi overpressure range, where it is assumed they cannot be blown out.)

Figure 13 (which shows the independent effects of airblast and fire) was modified by the data in Figure 15 to derive Figure 16, which shows the shifts, toward ground zero, of the 10 percent, 25 percent, 50 percent, and 75 percent burnout ranges due to airblast blowout of two-thirds of the initial fire starts. Figure 16 indicates that airblast blowout of fires becomes relatively more significant (1) at lower weapon yields and (2) at higher levels of thermal damage, and that the degree of improvement is somewhat subjective, depending on the levels of thermal damage and the weapon yield as illustrated in the following example for a 1-MT burst.

For example, for a 1-MT burst, airblast blowout of initial fires reduces the maximum burnout from about 92 percent to 69 percent, a reduction of 25 percent. At approximately 34,000 feet the burnout is reduced from approximately 60 percent to 47 percent, a reduction of 20 percent, and the 60 percent burnout line now occurs at approximately 31,000 feet, a reduction in area of approximately 15 percent. At approximately 37,000 feet the burnout is reduced from approximately 50 percent to 44 percent, a reduction of approximately 12 percent, and the 50 percent burnout line shifts to 35,000 feet, a reduction in area of approximately 10 percent. Beyond approximately 40,000 feet, where the burnout is 40 percent or less, there is no reduction in fire damage since the initial fires occur beyond the range at which it is assumed they can be blown out (2-psi overpressure).

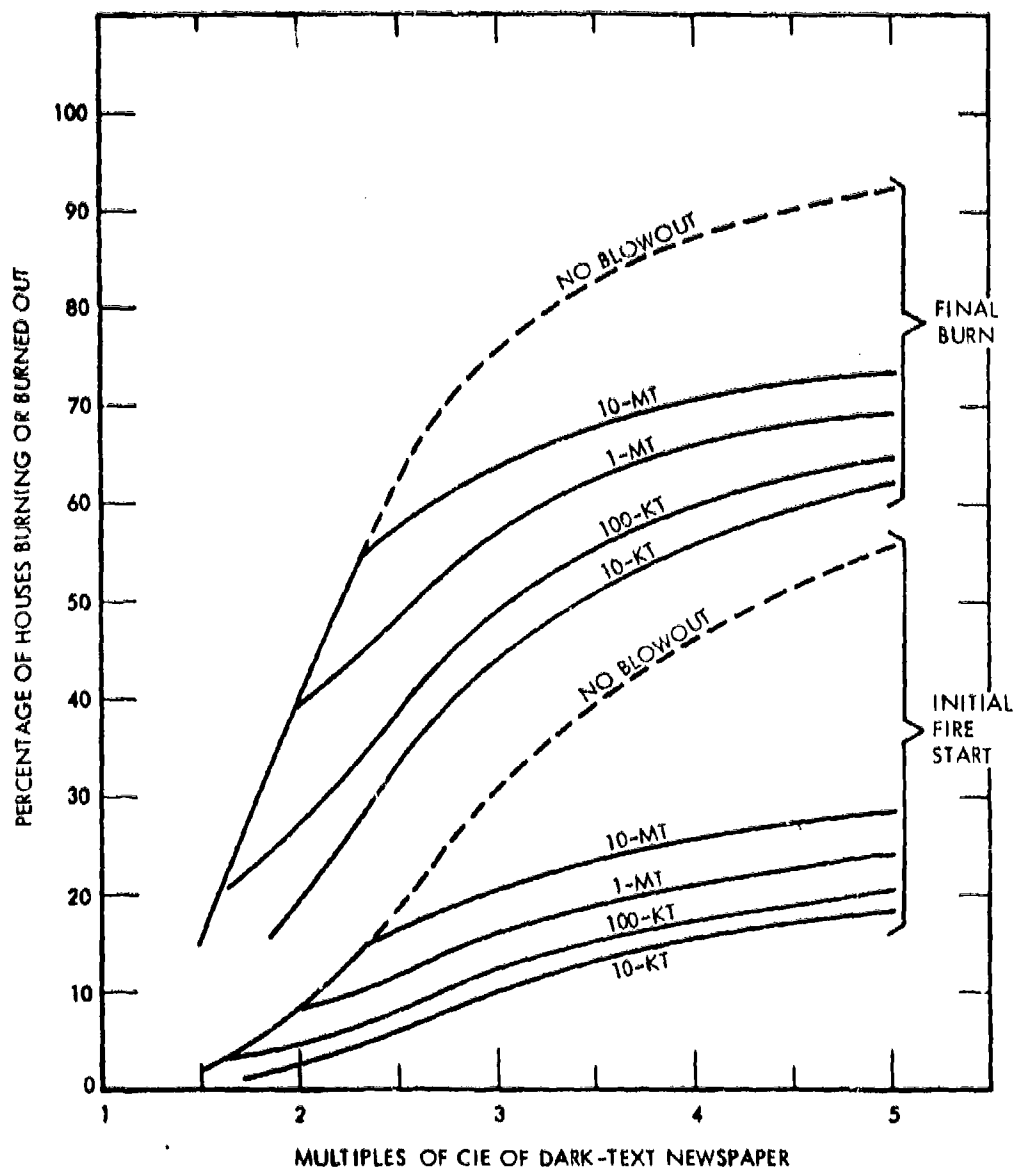


Figure 15. Fraction of single-family residences initially ignited and finally burned up, assuming airblast of 2 psi or greater blows out ignitions to reduce initial fire starts by a factor of 3.

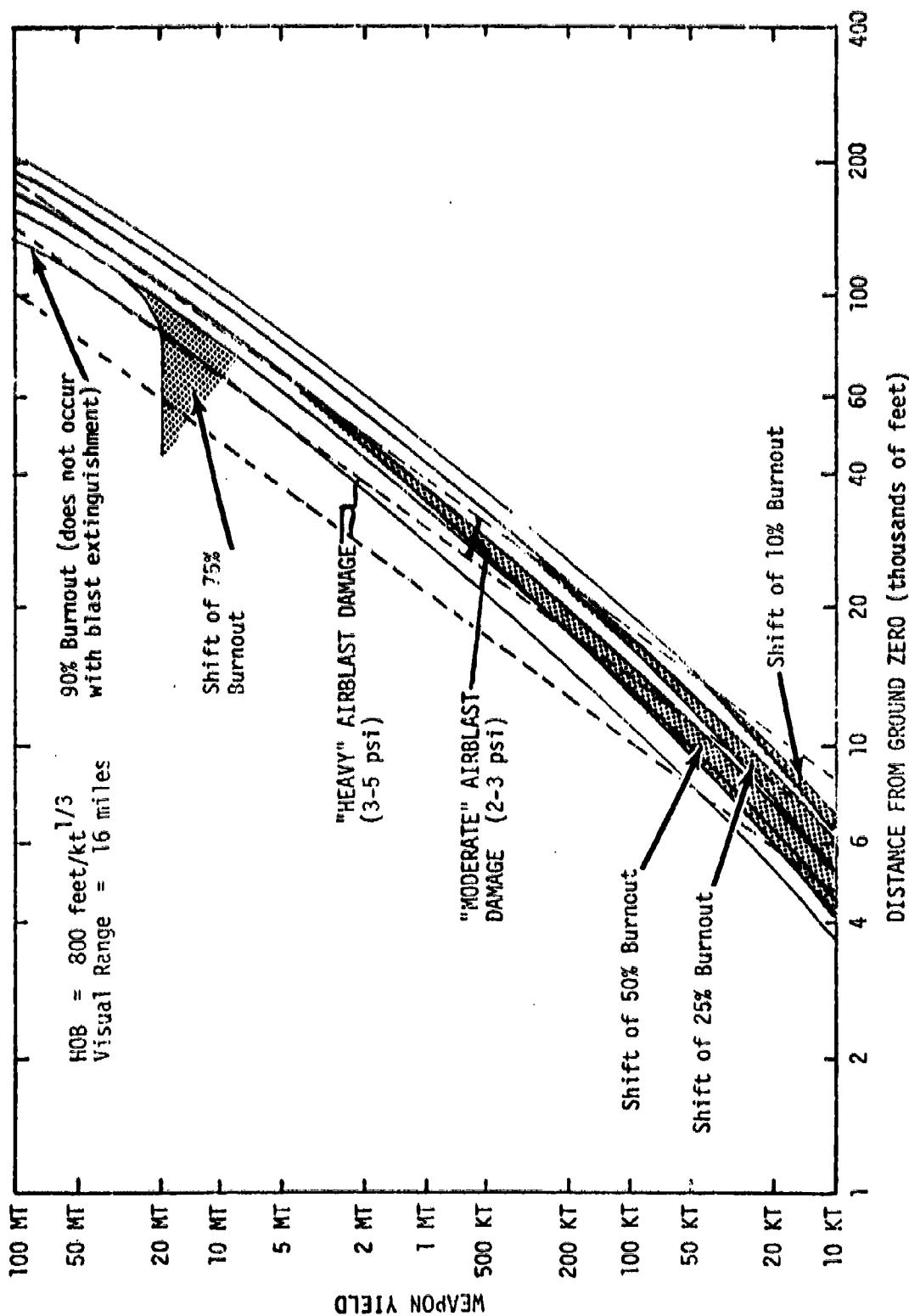


Figure 16. Airblast and thermal damage zones in single-family residential areas assuming airblast greater than 2 psi reduces initial fire starts by a factor of three.

Plots similar to 15 and 16 can be constructed for other initial conditions, and Figure 14 suggests the desirability of doing so. In his analysis of the effects of airblast on fire, Goodale used as a base of departure a calculation of the probability of fire starts in essentially the same manner as that given by Martin (Reference 3). This calculation includes consideration of the numbers of various types of fuels in rooms, the probability that each type of fuel would be exposed, and the probability that the exposed fuels would result in room "flashover", a significant fire. As shown in Figure 14, the maximum probability of primary fire starts that Goodale found for residential occupancy was approximately 0.3, assuming uncovered windows and no synergistic airblast effects. (For the Five Cities Study, probabilities derived from fuel content survey values given by Martin range from 0.32 for single-family residences in San Jose to about 0.76 for certain single-family residences in Providence.)

Goodale's maximum probability is just over one-half of the maximum used to derive Figure 15. Thus, a similar figure based on Goodale's results could be derived from the dashed lines of Figure 11. This has been done in Figure 17, and that figure has in turn been used to derive Figure 18.

Comparison of Figures 17 and 18 with Figures 15 and 16 indicates the importance of assuming a smaller fraction of initial ignitions. Whereas the 40 percent burnout line in Figure 16 is unchanged by airblast from a 1-MT weapon, the 40 percent burnout level in Figure 17 is reduced to 31 percent, an improvement of 25 percent and the maximum burnout is reduced from 70 percent to 50 percent, an improvement of 38 percent.

In summary, while airblast blowout of fires in areas of relatively high thermal damage may significantly reduce the degree of final burnout, particularly for the case of relatively low-yield weapons, areas



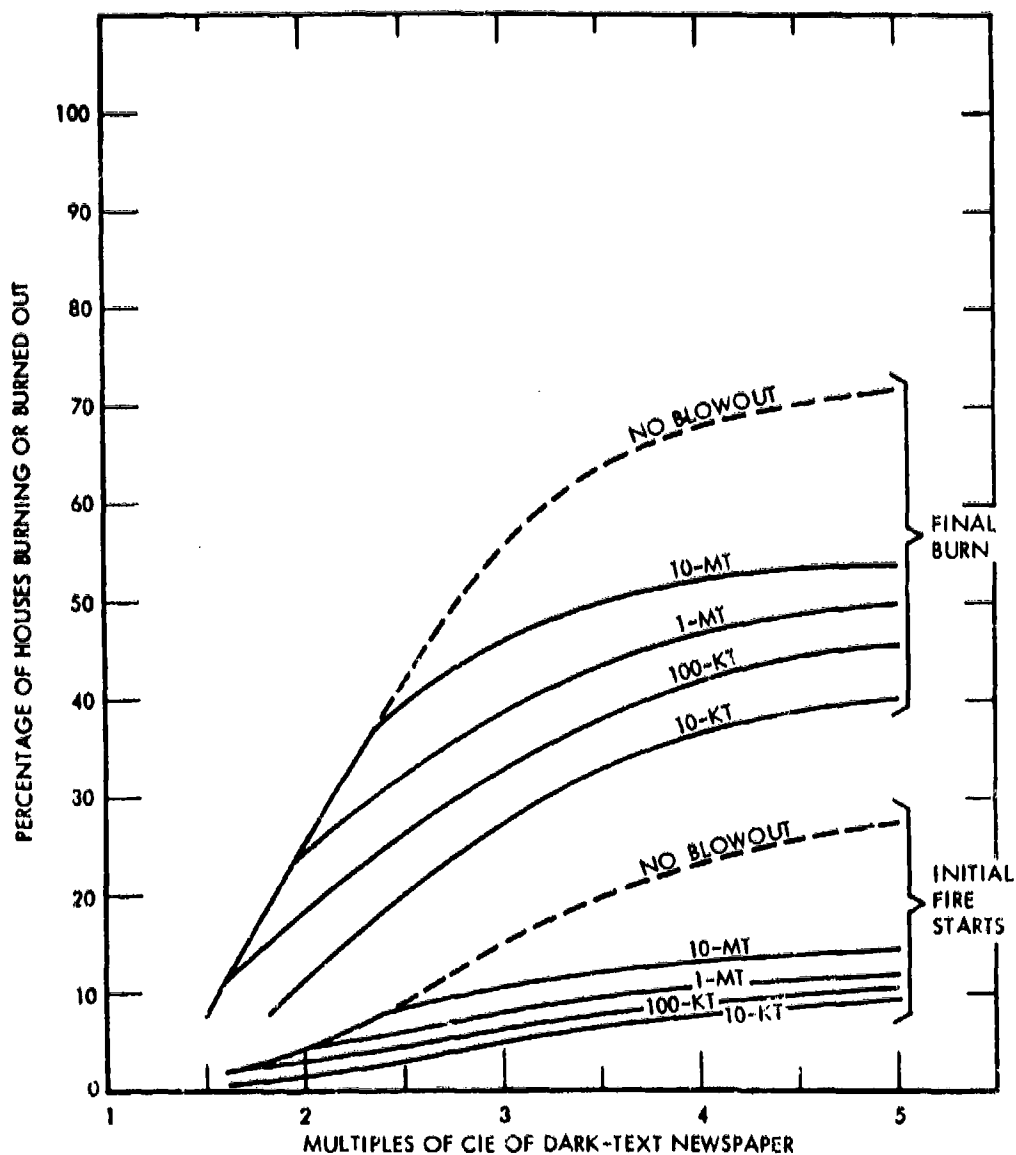


Figure 17. Fraction of single-family residences initially ignited and finally burned up, assuming airstblast of 2 psi or greater blow out ignitions to reduce initial fire starts by a factor of 3. (Based on data from Goodale and Martin. Initial ignitions without synergistic effects are half of those shown in Figure 15.)

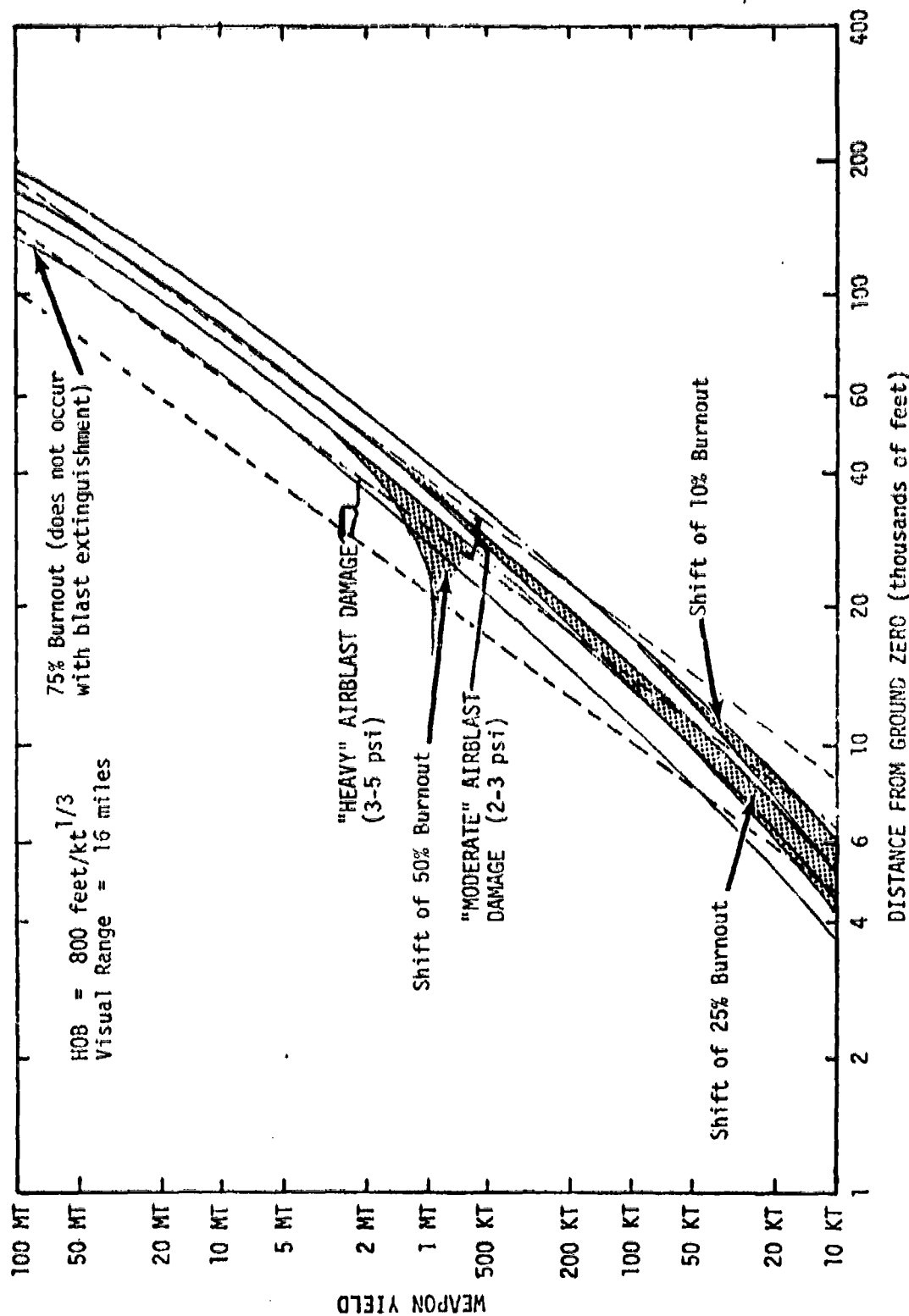


Figure 18. Airblast and thermal damage levels in single-family residential areas assuming initial ignitions are one-half those used for Figure 16, and that airblast > 2 psi reduces fire starts by a factor of 3.

of lesser thermal damage may be relatively unaffected, particularly in the case of megaton-yield weapons.

### Secondary Fires

Secondary fires are those that result from airblast damage. Their causes include overturned gas appliances, broken gas lines, and electrical short-circuits. McAuliffe and Moll (Reference 17) studied secondary fires resulting from the atomic attacks on Hiroshima and Nagasaki and compared their results with data from conventional bombings, explosive disasters, earthquakes, and tornadoes. Their major conclusion was that secondary ignitions\* occur with an overall average frequency of 0.006 for each 1000 square feet of floor space, provided airblast peak overpressure is at least 2 psi. The frequency of secondary ignitions appears to be relatively insensitive to higher overpressures. Table 4 summarizes their findings on secondary ignitions as a function of type of building, type of occupancy, and time of day.

Table 4 indicates that secondary ignitions will occur in 1 percent to 3 percent of typical wood or brick houses with 1500 square feet of floor space. In Figure 19, a constant 2 percent is added to the primary (initial) fire starts shown in Figure 15, for areas within the 2-psi overpressure range where airblast can start secondary fires. Figure 19 indicates that secondary fires contribute little to the overall fire problem caused by megaton weapons. For example, for a 1-MT weapon the radiant exposure which would eventually result in 50 percent burnout (after reduction of significant primary fires by a factor of 3) shifts from a newspaper CIE of approximately 2.55 to 2.25. This results in only a small increase in the area subjected to 50 percent burnout or greater. At the lower yields and lower levels of burnout secondary

---

\* McAuliffe and Moll sometimes used the terms "fire" and "ignition" interchangeably; but their results are apparently presented for ignitions which will cause a flaming area about the size of a folded newspaper, some of which will not result in significant fires.

Table 4. Factors for calculating secondary ignitions.  
(Source: Reference 17.)

FREQUENCY OF SECONDARY IGNITIONS AS A FUNCTION OF BUILDING TYPE*	
<u>Type of Structure</u>	<u>Frequency of Secondary Ignitions (for each 1,000 square feet of floor area)</u>
Wood	0.019
Brick	0.017
Steel	0.004
Concrete	0.002

MULTIPLYING FACTOR FOR TYPES OF BUILDING OCCUPANCIES	
<u>Type of Occupancy</u>	<u>Multiplying Factor</u>
Public	0.4
Mercantile	0.5
Residential	0.5
Manufacturing	1.0
Miscellaneous	10.0

MULTIPLYING FACTOR FOR TIME OF DAY	
<u>Time of Day</u>	<u>Multiplying Factor</u>
Night	0.5
Day (other than mealtimes)	1.0
Mealtimes	2.0

Example: Frequency of secondary ignitions in 1,500 square-foot wood residences during daytime equals

$$0.019 \times 1.5 \times 0.5 \times 1.0 = 0.0142$$

secondary ignitions per residence.

\* Based on surveys of Hiroshima and Nagasaki buildings.

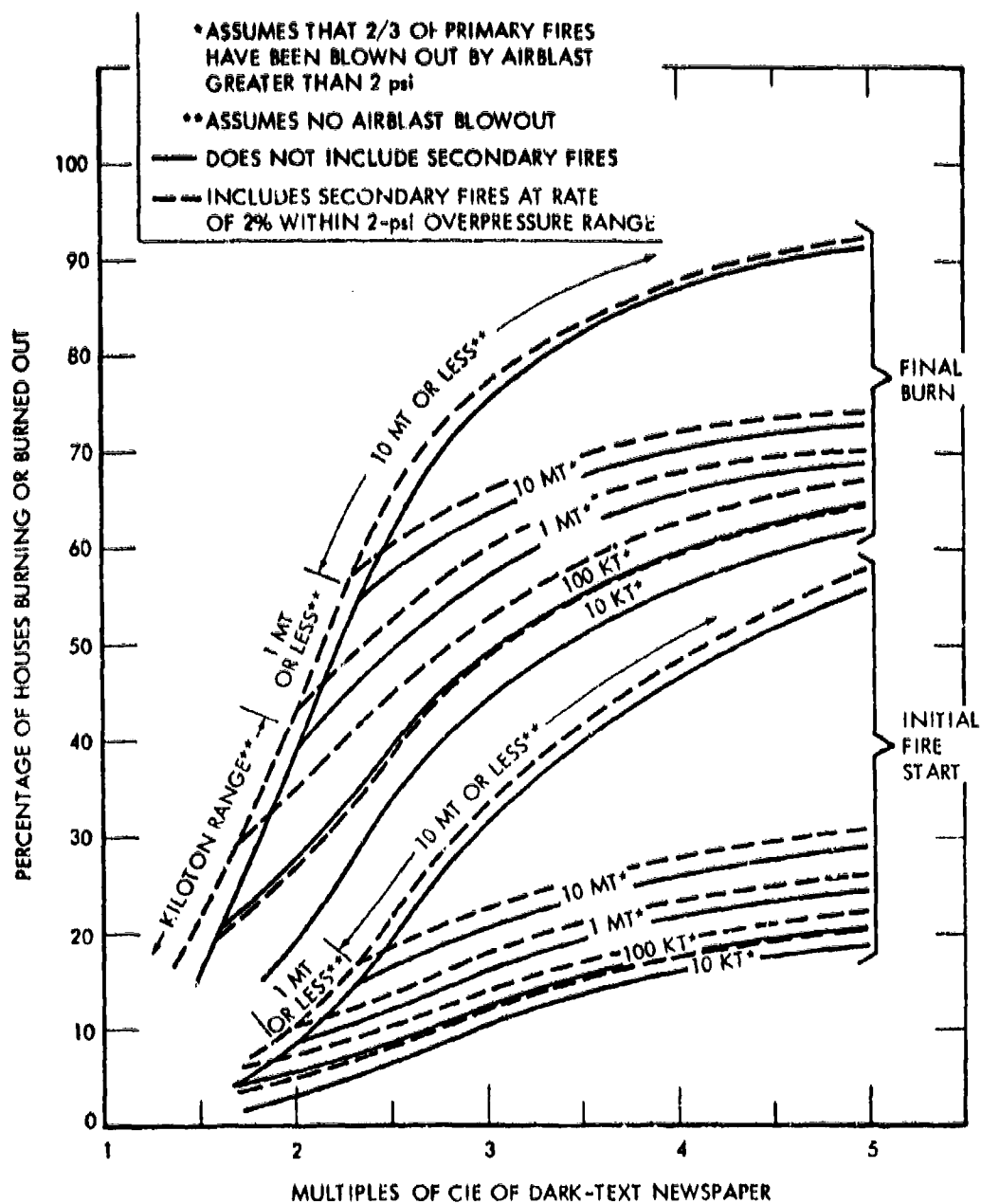


Figure 19. Effect of 2 percent of single-family residences suffering a secondary fire.

fires become relatively more significant. For example, for a 10-kt weapon, secondary fires may cause the 25 percent burnout isodamage line to shift back approximately midway between the 25 percent burnout range extremes representing no blowout of fires by airblast and blowout of two-thirds of the significant primary fire starts.

#### Other Synergistic Effects of Airblast

The thermal pulse precedes the airblast but some thermal radiation continues to be emitted from the fireball after the passage of the airblast wave. For large, megaton-yield weapons at distances where the overpressure is in the vicinity of 5 psi or greater, the thermal radiation emitted following passage of the airblast wave is sufficient to ignite some combustible materials exposed by the airblast wave. However, the incidence of fires within these distances is so high that the contribution of primary fires following the airblast should not be significant.

Airblast has a number of effects on the spread of fires. Airblast modifies buildings in a number of ways that permit fire to spread faster. Building interior furnishings are disrupted, debris is created, and additional combustible surfaces are exposed to provide fuel. Windows are broken permitting more oxygen to reach the flames. The faster burning fires burn hotter and broken windows in adjacent buildings allow more radiant energy from the fires to shine on interior furnishings. Debris between buildings may speed fire spread. Airblast also inhibits the ability to fight fires. Fire-fighting equipment may be damaged and personnel may be injured by airblast effects. Debris may block entry of fire trucks. The water supply may be cut off due to broken water mains and damaged pumping stations. Communications will be disrupted. Fire fighting by property owners will be inhibited by injuries or preoccupation with rescue or escape efforts. Methods of quantifying the significance of these effects have not been found.

## SECTION 5

### CONCLUSIONS AND RECOMMENDATIONS

The summary in Table 1 of the vulnerabilities of buildings and building components to airblast permits one to select an HOB and define airblast damage zones for urban areas. The HOB chosen in this study ( $800 \text{ feet/kt}^{1/3}$ ) maximizes the area subjected to peak overpressures of 5 to 10 psi and produces 2-psi overpressure at near maximum range. However, the broad results of this study are not strongly dependent on the chosen HOB or definition of damage zones; other values can be used.

Curves and plots have been found in the literature that permit thermal damage in areas of single-family residences to be directly related to certain weapon parameters. Similarly available information has not been found for other types of areas (multi-family residential, commercial, etc) but when it is available, simple relationships among thermal damage, weapon yield, and ground range (for various heights of burst) can be derived with a relatively modest effort using the methods in this report.

These methods, which make use of an "index of thermal damage" (the CIE of dark-text newspaper was chosen) involve first developing a relationship between the index and weapon yield and range for a particular height of burst (as in Figure 7); then relating the index to the fraction of initial fire starts in an area (as in Figures 9 and 11); and finally relating the fraction of initial starts to the fraction of structures ultimately burned out in the area (as in Figures 10 and 11). The methods include techniques for determining certain synergistic effects of blast on initial fire starts (Figure 15), and the

construction of plots of blast and thermal damage as a function of weapon parameters (Figures 13, 16, and 18).

Based on the assumptions and techniques used in this report it is concluded that, for most weapon yields of strategic interest, a burst at a moderate height-of-burst with generally clear atmospheric conditions will produce thermal effects which subjectively seem more severe than airblast effects; e.g., for a 1-MT burst, approximately 25 percent to 40 percent of single-family residences will burn up at a range where the airblast peak overpressure of 2 psi will create light to moderate airblast damage. Extinguishment of initial fires by airblast reduces the severity of the fire damage and the reduction becomes relatively more significant for (1) smaller weapon yields and (2) areas of higher degrees of fire damage. Whether or not the degree of improvement is greatly significant is a matter of subjective judgment. For example, for the case of a 1-MT weapon yield and single-family residential areas in which one-half of the residences would burn up, airblast blowout of initial fires may reduce the fraction of burned-up homes by 25 percent to 35 percent, which seems significant. For higher levels of thermal damage the percentage of reduction of fires is relatively greater; however, areas where 25 percent to 40 percent of the residences could be expected to burn up are beyond the range where it is assumed that airblast from the 1-MT weapon could blow out fires.

It must be emphasized that such conclusions should not be accepted wholeheartedly without recognizing the high degree of uncertainty in the data and the analytical results. General conclusions regarding airblast/thermal phenomena and effects on cities may be completely dominated by the circumstances which apply to any one specific situation. For example, an overcast day or a day with a high degree of relative humidity would probably produce significantly different results. A different theater of operation or a different scenario, such as a tactical nuclear engagement in Europe or a MIRV attack, requires data and analysis tailored to those circumstances.



The contribution of secondary fires created by the airblast to the total fire damage is insignificant for megaton yield weapons. However, in the case of low-yield weapons such secondary fires may contribute a significant fraction of fires in areas of relatively light or moderate fire damage and can be analyzed as shown in Figure 19.

The various steps used to evaluate thermal damage in this report incorporate a number of assumptions, but evaluating the sensitivity of the entire process to these assumptions was beyond the scope of this study. Areas in which additional information is needed were found. These included areas in which available sources were contradictory or in which pertinent information had not yet been developed.

Among the more apparent areas which should be explored are the following:

1. Methods should be developed for quantifying the effect of blast damage on both fire spread and the degradation of fire fighting capabilities. (No such information was found in the course of this study.)
2. Better data are needed on the relationships between thermal exposure and probability of initial ignitions. (Contradictory data were found.) Also, the effect of factors such as Federal regulations requiring fibers to be fire-resistant should be analyzed.
3. Information is needed on the effects of long duration blast waves on fire extinguishment. (Available information is from experiments with flow durations similar to those of 0.05 kt weapons and below.)
4. Fire-spread information for areas that do not solely consist of single-family residential structures was not readily available. (The various models available could probably be used to derive information similar to that shown in Figure 10.)

5. The relationship between airblast magnitude and duration and extinguishment of fires needs to be more accurately determined. Using a fire-extinguishment threshold other than 2-psi peak overpressure might significantly alter the results of this study.
6. The sensitivities of the process used to determine thermal damage to such factors as the choice of CIE of newspapers as an index of damage; burst and atmosphere conditions; and methods for calculating both initial fire starts and blast extinguishment of these initial fires, need to be established.
7. The fire spread and blast-fire interaction models used should be modified wherever possible to incorporate knowledge derived from realistic experiments.
8. Most of the studies of nuclear airblast and fires in urban areas are based on a scenario of a single 1-MT to 5-MT weapon exploded at a low HOB or even at ground level. Other scenarios and situations should be analyzed. For example, a MIRV-type attack on U.S. cities would produce significantly different results from those for a single large-yield burst. Windows and screens attenuate incident thermal energy by approximately 50 percent and if they are removed by airblast the area of significant fire starts due to thermal radiation from a subsequent burst might be more than doubled. The analysis of a tactical nuclear engagement in a European theater of operations is of considerable interest. Data should be gathered which pertain to such a scenario and analyzed in the context of the different weapon yields, HOBs, weather conditions, and civilian environments which apply.

However, before any detailed analysis or extensive data collection effort is initiated, a perspective is needed on the factors which are likely to dominate any given scenario. For example, to what extent does the movement of mass fires dominate? There is little purpose in analyzing initial ignitions and the local spread of fires in detail if it is

likely that mass fires will develop and spread beyond the range of initial ignitions. As another example, to what extent are scenarios dominated by atmospheric conditions? Most of the analyses are for quite clear atmospheric conditions and assume that only materials within line-of-sight of the fireball can ignite. It would be of considerable interest to have a perspective on the likelihood of occurrence of cloud cover, rain, smog, snow on the ground, etc., and the resulting modification of the thermal effects. Ignitions due to scattered radiation should be included in such analyses.

## REFERENCES

1. See insert.
2. The Effects of Nuclear Weapons, U.S. Atomic Energy Commission, Washington, D.C., Samuel Glasstone, Editor, Revised February 1964.
3. The Role of Fire in Nuclear Warfare, S.B. Martin, URS Research Company, San Mateo, California 94402, DNA 2692F, URS 764, 23 August 1974.
4. Nuclear Weapons, V.A. Mikhaylov and I.A. Naumenko, Yadernaya Fizika i Yadernoye Oruzhiye (Nuclear Physics and Nuclear Weapons), Moscow, 1966, pp-122-179. Air Force Systems Command, Foreign Technology Division Report No. FTD-MT-24-1271-71 (AD 745857), 28 April 1972.
5. Failure Strengths of Wall Panels Under Explosive Loading, C. Wilton, et al, (Minutes of the Explosive Safety Seminar [15th], San Francisco, CA, 18-20 September 1973, Volume I), DoD Explosives Safety Board, Washington, D.C., AD 775 580, pp. 551-587, 20 September 1973.
6. Existing Structures Evaluation, Part IV: Two-Way Action Walls, C.K. Wiehle, and J.L. Bockholt, Stanford Research Institute, Menlo Park, California 94052, SRI Project 6300, September 1970.
7. Probabilistic Air Blast Failure Criteria for Urban Structures, E.E. Pickering, and H.S. Bockholt, Stanford Research Institute, Menlo Park, California 94052, (AD 738558), November 1971.
8. Summary Report-House Damage Assessment, C. Wilton and B. Gabrielsen, URS Research Company, San Mateo, California 94402, DNA 2906F, URS 788-5, January 1973.
9. Blast Response to Five NFSS Buildings, C.K. Wiehle, and J.L. Bockholt, Stanford Research Institute, Menlo Park, California 94025, October 1971.

10. Effects of Air Blast on Urban Fires, Final Report, Thomas Goodale, URS Research Company, San Mateo, California, URS 7009-4 (AD 723429), December 1970.
11. Significant Primary Fires from Nuclear Detonations, Final Report, Robert M. Rodden, Stanford Research Institute, Menlo Park, California, No. 4536-433 (AD 479980), January 1966.
12. Development and Application of an Interim Fire-Behavior Model, Final Report, and Appendix C: Fire Damage to San Jose in the Five-City Attack, S. Martin, R. Ramstad, and C. Colvin, URS Research Company, Burlingame, California, URS 674-3, April 1968.
13. An Investigation of Ignition and Fire Spread Characteristics of Cloth Covered Upholstery and Carpeting, B. T. Lee and L. L. Wiltshire, Naval Radiological Defense Laboratory, San Francisco, CA 94135. Report No. NRDL-TR-69-68, 8 July 1969.
14. Forest Fuels Blast Studies Interim Report, V. N. Tramontini and P. R. Dahl, University of California, Los Angeles, California, No. 53-15, June 1953.
15. The Ignition Hazard to Urban Interiors During Nuclear Attack Due to Burning Curtain Fragments Transported by Blast, T. Goodale, URS Research Company, San Mateo, California, URS 7030-5 (AD 740821), December 1971.
16. Fire Spread Model Adaptation, A. N. Takata, IIT Research Institute, Chicago, Illinois 60616, Final Report IITRI J 6263 (AD 735989), October 1972.
17. Secondary Ignitions in Nuclear Attack, J. McAuliffe and K. Moll, Stanford Research Institute, Menlo Park, California 94025, SRI Project 5106 (AD 625173), July 1965.

## DISTRIBUTION LIST

### DEPARTMENT OF DEFENSE

Assistant to the Secretary of Defense  
Atomic Energy  
ATTN: Honorable D. R. Cotter

Defense Documentation Center  
12 cy ATTN: TC

Defense Civil Preparedness Agency  
ATTN: Administrative Officer

Dir. of Defense Resch. & Engineering  
ATTN: AD/SW  
ATTN: DA/NP  
ATTN: DD/TWP  
ATTN: DD/T&SS

Commander  
Field Command  
Defense Nuclear Agency  
ATTN: FCPR

Chief  
Livermore Division, Fld. Command DNA  
ATTN: FCPRL

Director  
Defense Nuclear Agency  
ATTN: STSI, Archives  
ATTN: DDST  
ATTN: SPSS  
ATTN: RATN

3 cy ATTN: STTL, Tech. Lib.

Director  
Command Control Tech. Ctr.  
ATTN: C610, Frank Moore

### DEPARTMENT OF THE ARMY

Assistant Secretary of the Army  
ATTN: Assistant for Research, R&D

Commander  
Harry Diamond Laboratories  
ATTN: Tech. Lib.

Commanding Officer  
U.S. Army Combat Developments Command  
ATTN: CPT Ader

### DEPARTMENT OF THE NAVY

Commander  
Naval Facilities Engineering Command  
ATTN: Code 0322C

Chief of Naval Research  
ATTN: Nicholas Perrone

Commander  
Naval Supply Systems Command  
ATTN: Code 0052

Naval Surface Weapons Center  
ATTN: Mr. Willard Derksen

### DEPARTMENT OF THE NAVY (Continued)

Naval Ship & Development Center  
ATTN: Mr. Tom Amrhein  
ATTN: Code 857

### DEPARTMENT OF THE AIR FORCE

AF Weapons Laboratory, AFSC  
ATTN: SUL

### ENERGY RESEARCH & DEVELOPMENT ADMINISTRATION

Union Carbide Corporation  
Hollifield National Laboratory  
ATTN: Librarian

### OTHER GOVERNMENT AGENCIES

Department of Agriculture  
Forest Service  
Forest Fire Laboratory  
ATTN: Mr. A. P. Brackebush

Department of Agriculture  
Forest Service  
Forest Fire Laboratory  
ATTN: Mr. Stanley Hirsch

Department of Agriculture  
Forest Service  
ATTN: Forest Fire Research

Department of Agriculture  
Forest Service  
ATTN: Mr. A. Droido

National Bureau of Standards  
ATTN: Dr. A. F. Robertson

National Bureau of Standards  
Office of Federal Building Technology  
ATTN: Dr. Charles G. Culver

National Bureau of Standards  
ATTN: Mr. William Parker

National Bureau of Standards  
ATTN: Fire Research Library

National Bureau of Standards  
ATTN: Executive Secretary

National Bureau of Standards  
Building Research Division  
ATTN: Mr. Irwin A. Benjamin

Department of Housing & Urban Development  
Program Planning & Control  
ATTN: Mr. Bert Greenglass

International Association of Fire Fighters  
ATTN: Mr. Howard McClennon, President

International Association of Fire Chiefs  
ATTN: Mr. Donald O'Brien

OTHER GOVERNMENT AGENCIES (Continued)

General Services Administration  
Director, Office of Preparedness  
ATTN: General Leslie Bray

General Services Administration  
Head, Fire Safety & Mobilization Planning Branch  
ATTN: Mr. Harold E. Nelson

DEPARTMENT OF DEFENSE CONTRACTORS

Dikewood Industries, Inc.  
ATTN: Al Wayne Davis

Factory Mutual Research Corporation  
ATTN: Dr. Raymond Friedman

Gage-Babcock & Associates, Inc.  
ATTN: Mr. B. M. Cohn

General Electric Company-TEMPO  
ATTN: Kenneth E. Gould  
11 cy ATTN: DASIAC

IIT Research Institute  
ATTN: Mr. Thomas E. Waterman

The Johns Hopkins University  
Applied Physics Laboratory  
ATTN: Dr. Robert M. Fristrom  
ATTN: Document Library

Institute for Defense Analyses  
ATTN: Dr. Abner Sachs

Mr. Kenneth Kaplan  
ATTN: Kenneth Kaplan

University of Minnesota  
Institute of Technology  
Department of Mechanical Engineering  
ATTN: Professor P. L. Blackshear, Jr.

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

National Academy of Sciences  
ATTN: Richard Park  
ATTN: Committee on Fire Research

National Fire Protection Association  
ATTN: Library

Research Triangle Institute  
ATTN: Mr. Edward L. Hill

Science Information Exchange  
ATTN: Mr. Vincent Maturi

Scientific Service, Inc.  
ATTN: Mr. Charles Wilton

Stanford Research Institute  
ATTN: Mr. Stanley B. Martin  
ATTN: Mr. Ray Alger, NOL Group  
ATTN: Mr. William L. White

Southwest Research Institute  
Department of Structural Research  
Fire Research Section  
ATTN: Mr. C. H. Yull

Systems Sciences, Inc.  
ATTN: Mr. John W. Crowley

FOREIGN DISTRIBUTION

Forest Fire Research Institute  
ATTN: The Information Center

University Karlsruhe (TH)  
Forschungsstelle fuer Brandschutztechnik  
ATTN: Dr. Ing. P. G. Seeger

INSERT TO

DASIAC TN 75-2 dated August 1975

COMBINED AIRBLAST AND INCENDIARY EFFECTS FROM NUCLEAR  
WEAPONS ON URBAN AREAS

The following reference relates to this document and has distribution limited to U.S. Government agencies only. This list is provided to all addressees on initial distribution except DDC/NTIS and foreign addressees.

